

Gluon polarization measurements at PHENIX

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for the PHENIX collaboration



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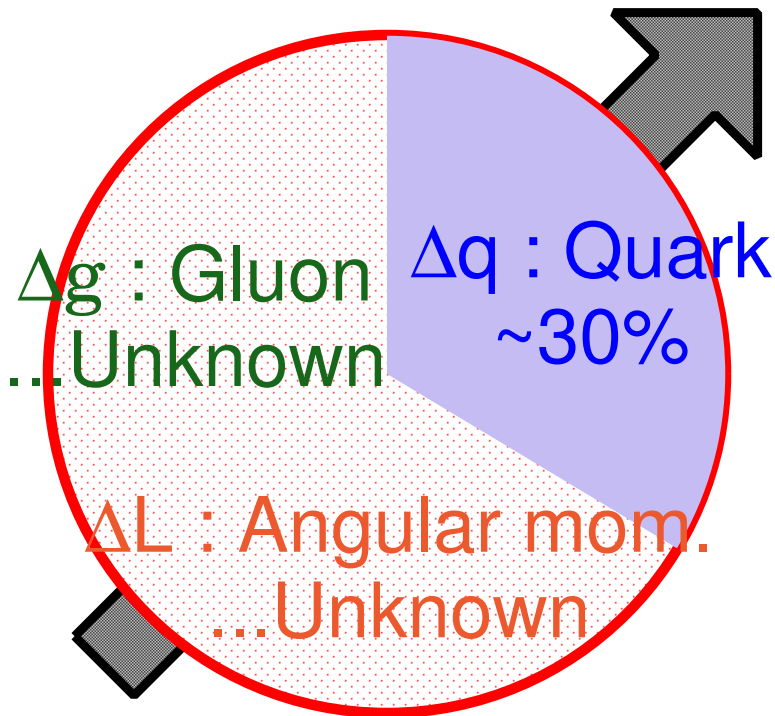
***as of March 2005**

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- > Physics motivation and the approach to Δg
- > RHIC-PHENIX experiment
- > Local Polarimeter
- > Relative Luminosity
- > Results of π^0 in run 5 (2005)
- > Other topics
- > Summary

Spin Physics at RHIC-PHENIX

How much does gluon spin align to proton spin?



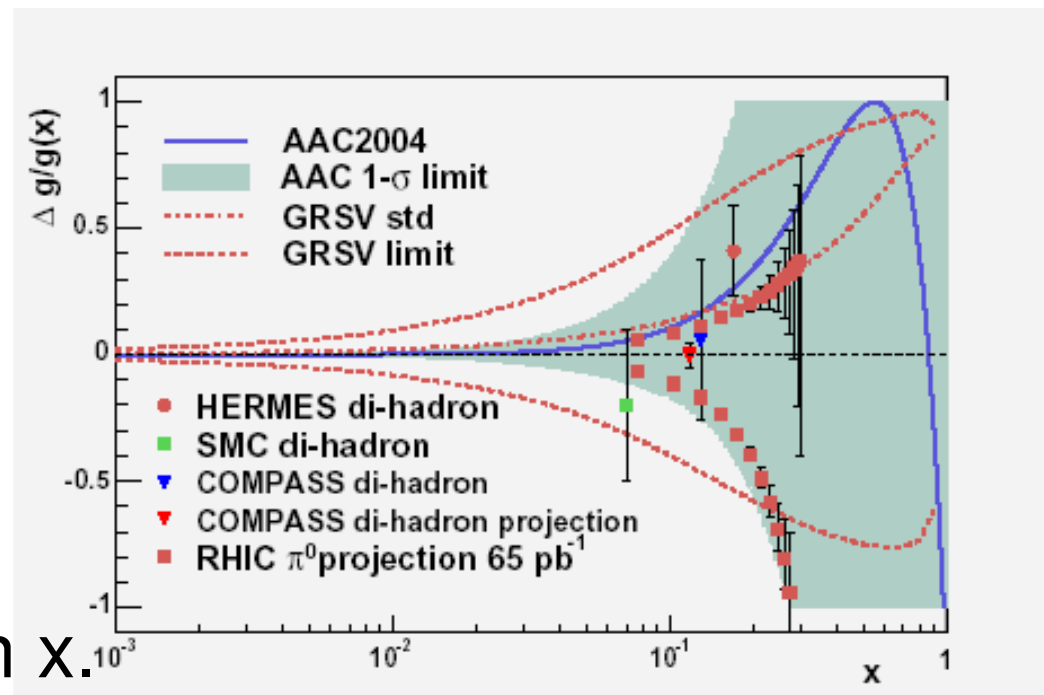
Proton structure, especially spin structure, is still unknown.



Shine a light on the gluon polarization Δg

$$\Delta g(x) = g_+^+(x) - g_+^-(x)$$

$g_+^{+(-)}(x)$: Probability to detect spin+ (spin-) gluon in spin+ proton as a function of Bjorken x .



Spin Physics at RHIC-PHENIX

How to measure Δg

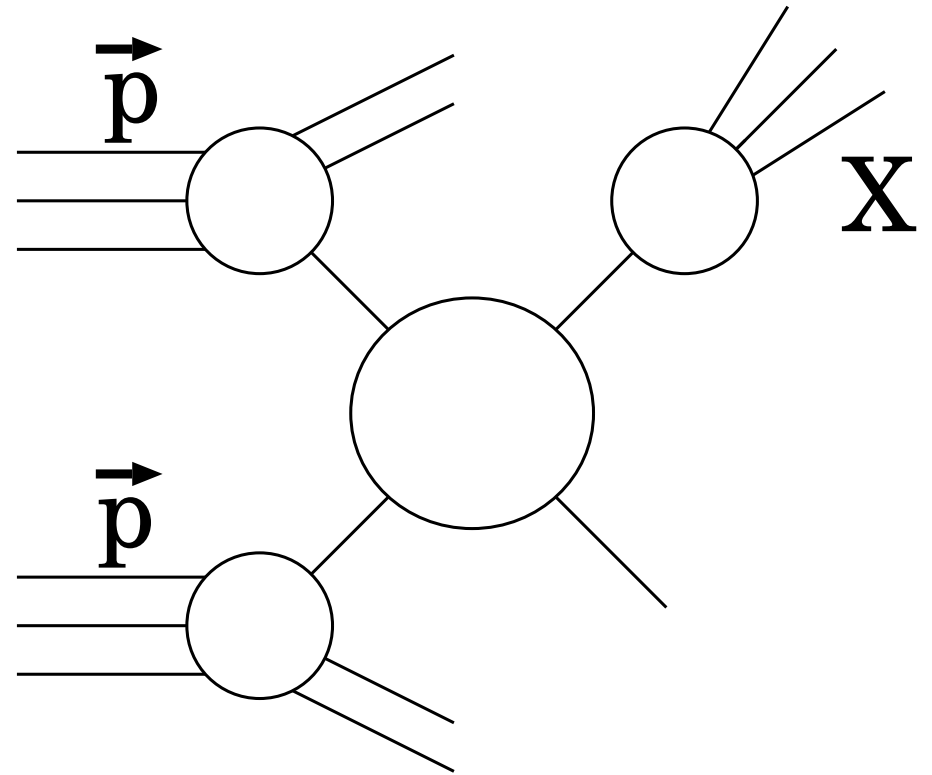
Measure A_{LL} in
 $\vec{p} \vec{p} \rightarrow X$ production.

X : Pions

Direct photon

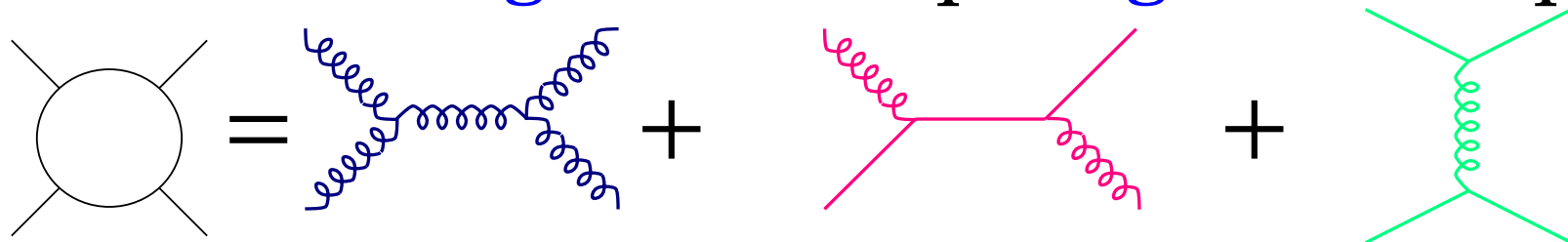
J/ψ

Any hadrons



$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

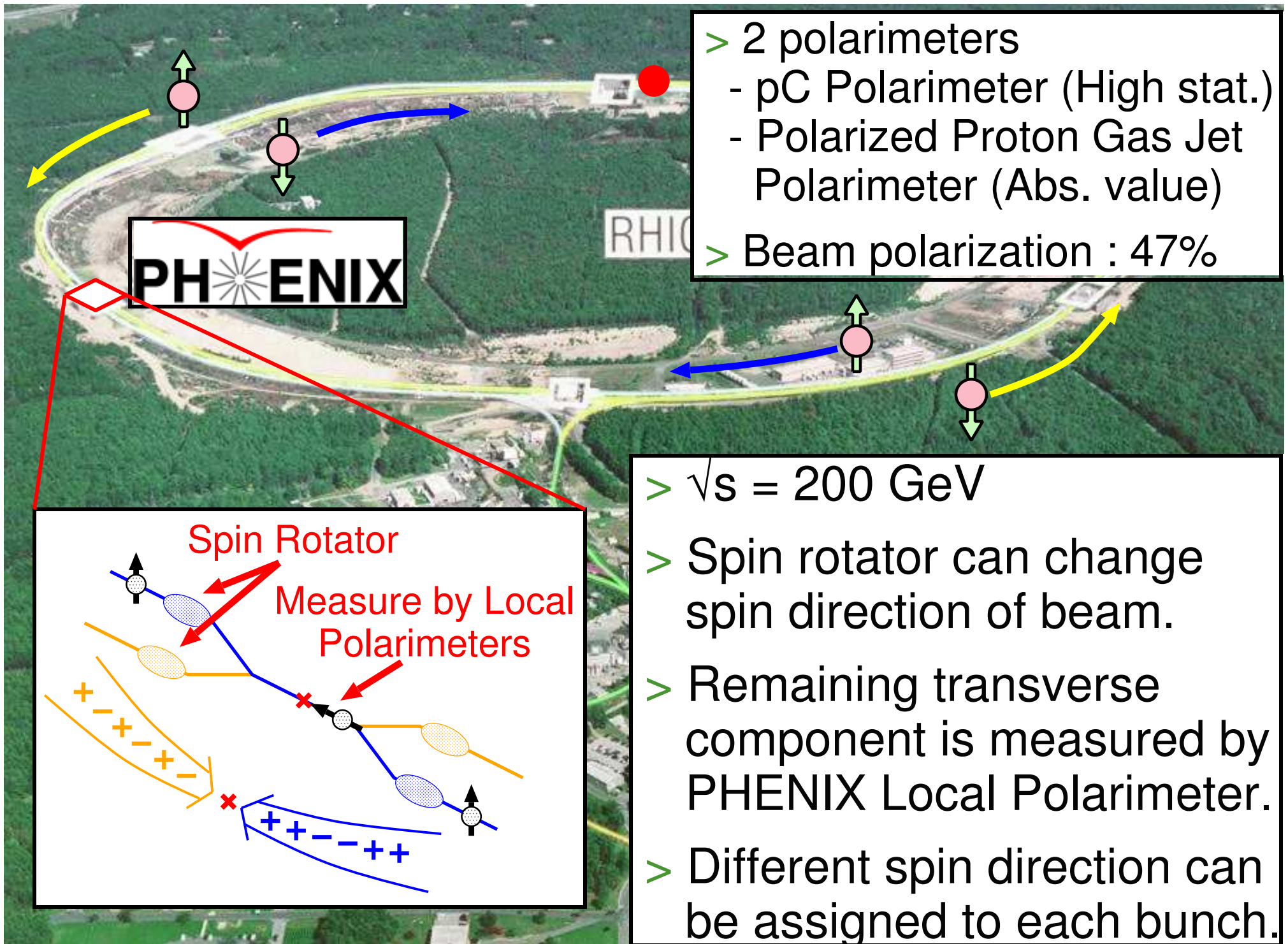
$$\sim \left[\omega_{gg} \left(\frac{\Delta g}{g} \right)^2 + \left[\omega_{gq} \left(\frac{\Delta q}{q} \right) \right] \left(\frac{\Delta g}{g} \right) + \left[\omega_{qq} \left(\frac{\Delta q}{q} \right)^2 \right] \right]$$



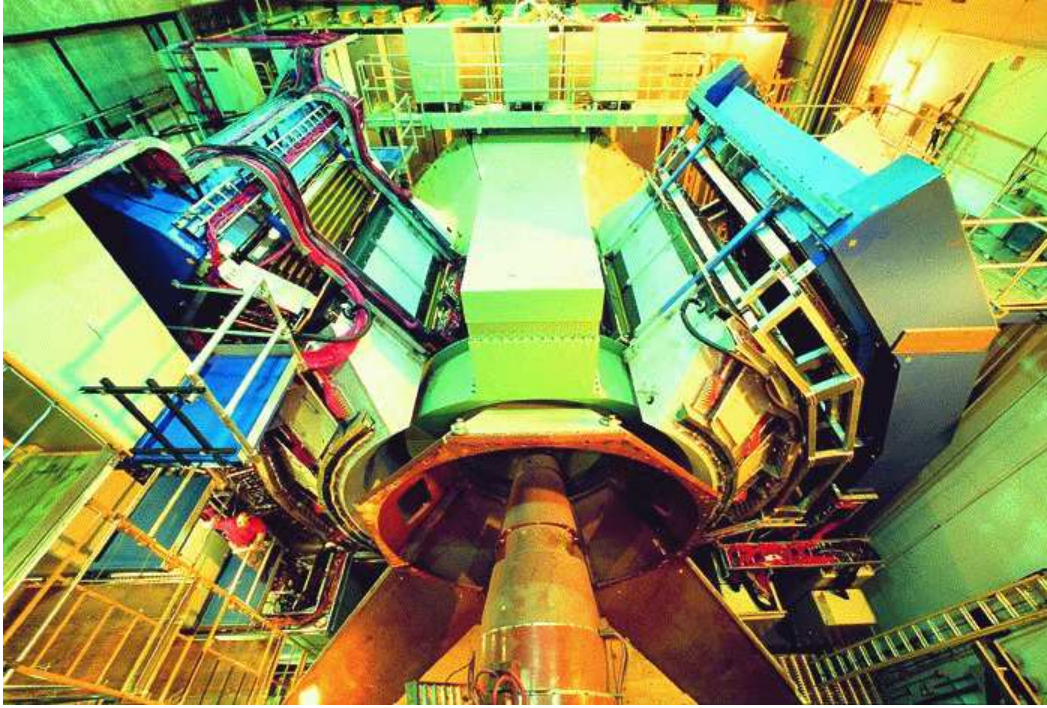
RHIC



RHIC



PHENIX



Beam-Beam-Counter & Zero Degree Counter

- > BBC : $3.0 < |\eta| < 3.9$
- > ZDC : $|\eta| > 6.6$ ($\theta < 2.8\text{mrad}$)
- > Minimum Bias Trigger (BBC)
- > Relative Luminosity (BBC&ZDC)
- > Local Polarimeter (ZDC)
- > Physics : Neutron (ZDC)

Central Arm

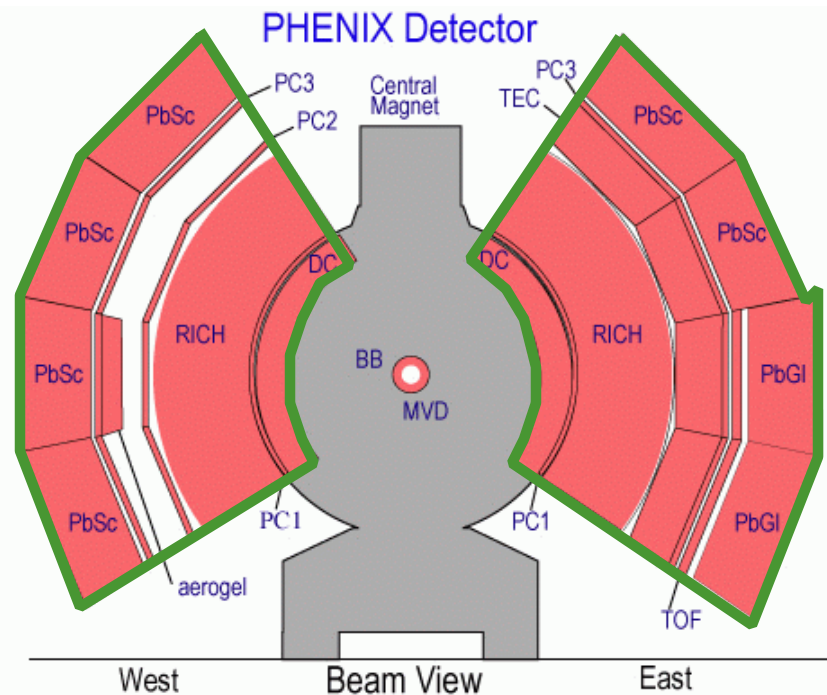
- > $|\eta| < 0.35$, $\Delta\phi = \pi$
- > Tracker, RICH, EMCal
- > Physics : π^0 , photon, charged hadrons, electron



Muon Arm

- > $1.2 < |\eta| < 2.4$
- > Muon Tracker, Muon Identifier
- > Physics : muon, J/ψ , W

PHENIX



Beam-Beam-Counter & Zero Degree Counter

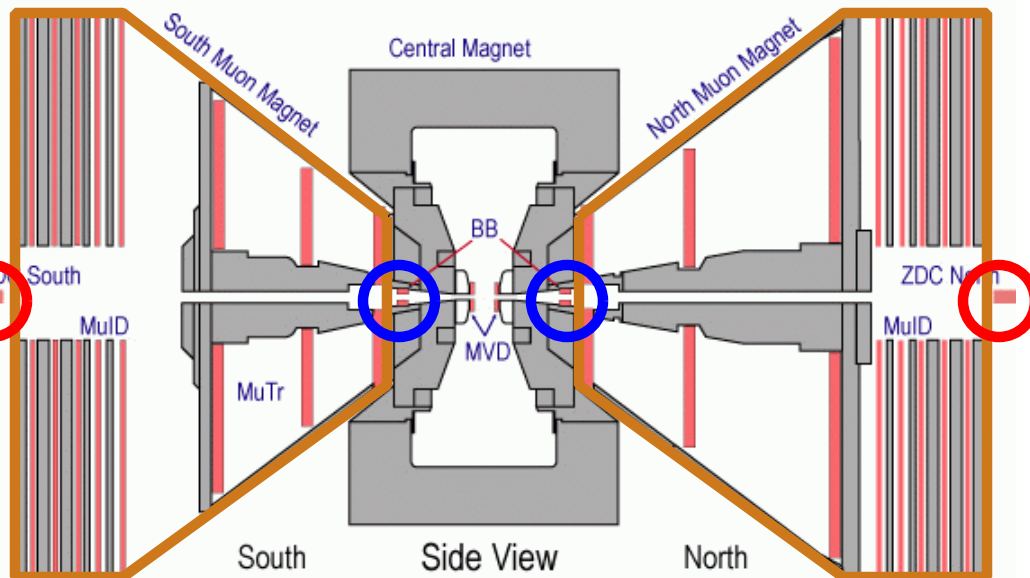
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Central Arm

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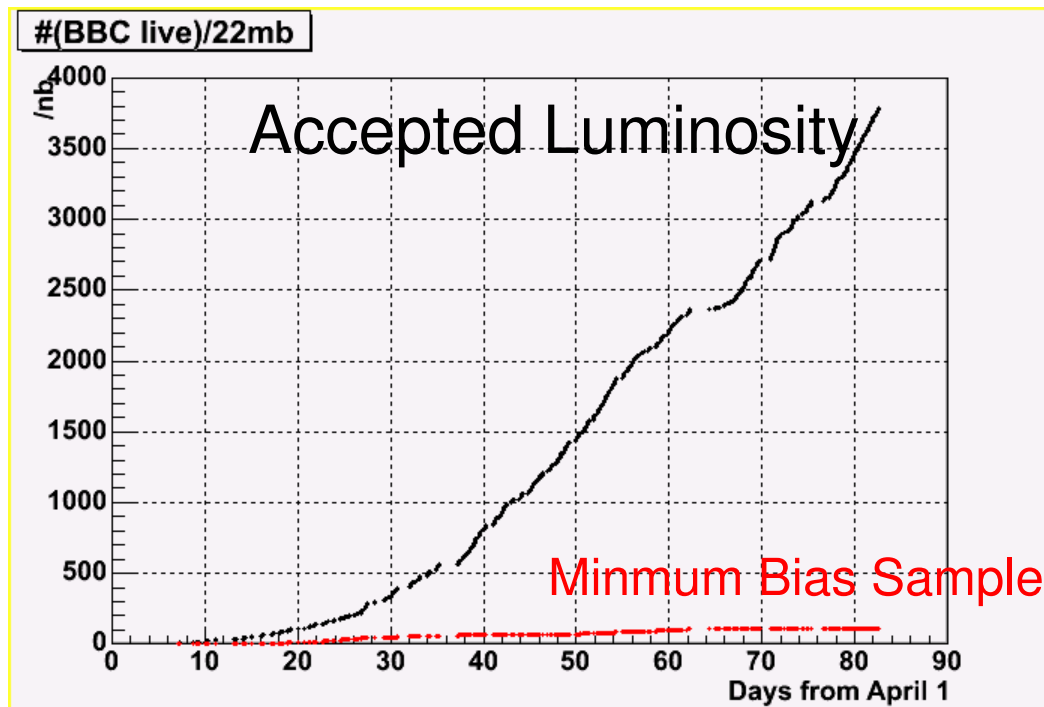
Luminosity & History

2001-2002 transverse spin run (First polarized proton run)
 $P=15\%$ $L=0.15 \text{ pb}^{-1}$

2003 longitudinal spin run
 $P=27\%$ $L=0.35 \text{ pb}^{-1}$ $\text{FOM}=1.86 \text{ nb}^{-1}$

2004 commissioning run (longitudinal spin)
 $P=40\%$ $L=0.12 \text{ pb}^{-1}$ $\text{FOM}=3.1 \text{ nb}^{-1}$

2005 longitudinal spin run (w/ short transverse spin run)
 $P=47\%$ $L=3.8 \text{ pb}^{-1}$ $\text{FOM}=185 \text{ nb}^{-1}$



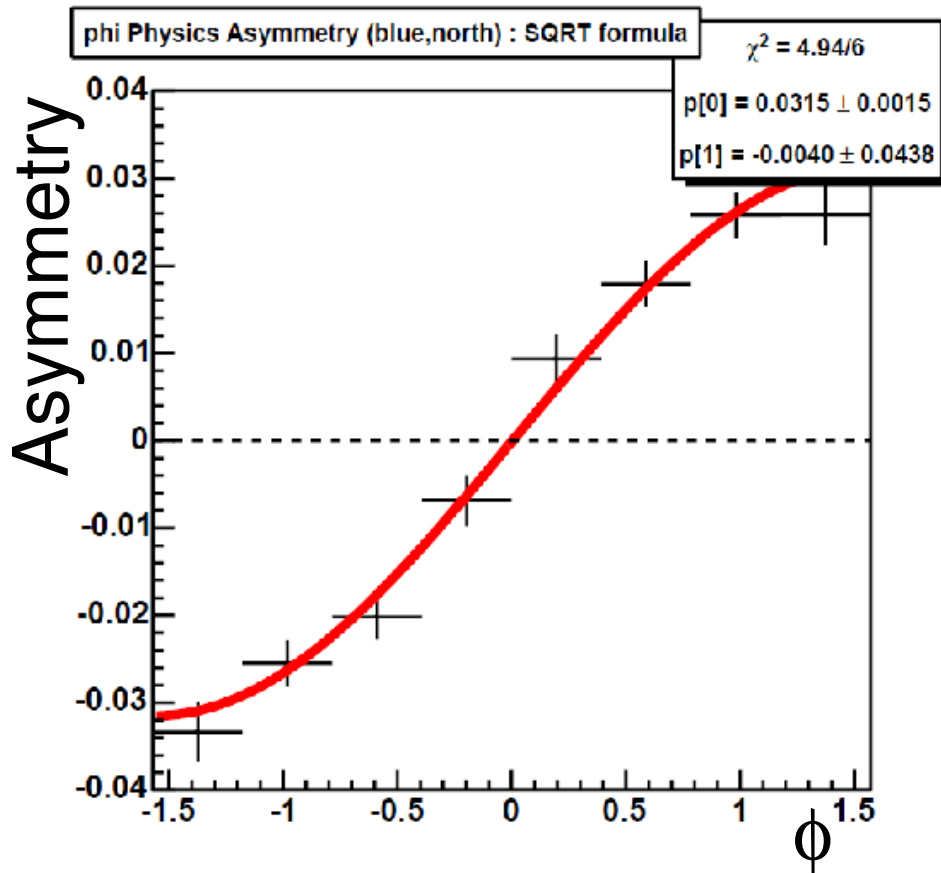
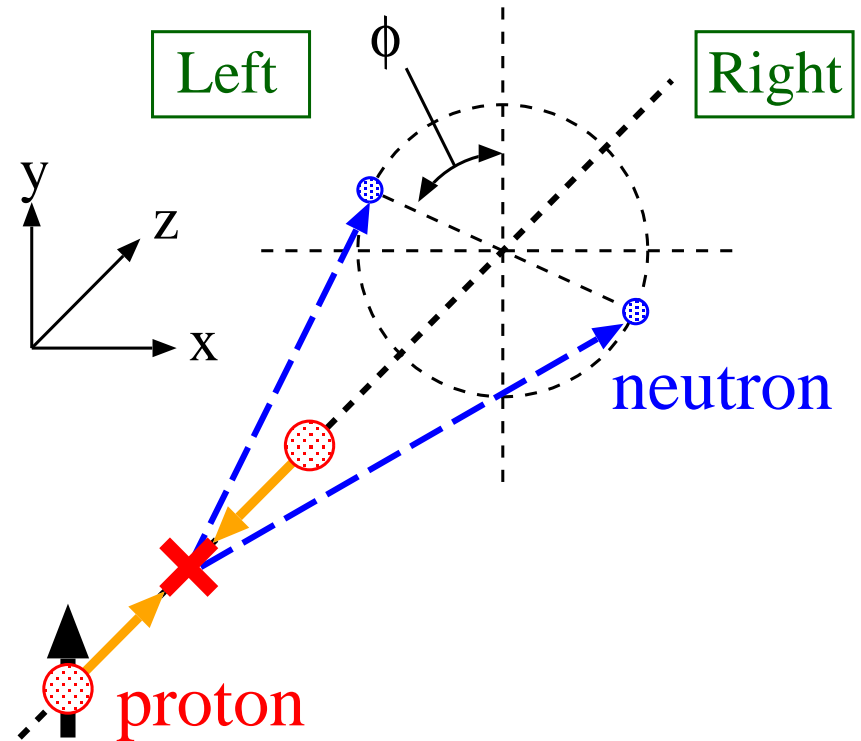
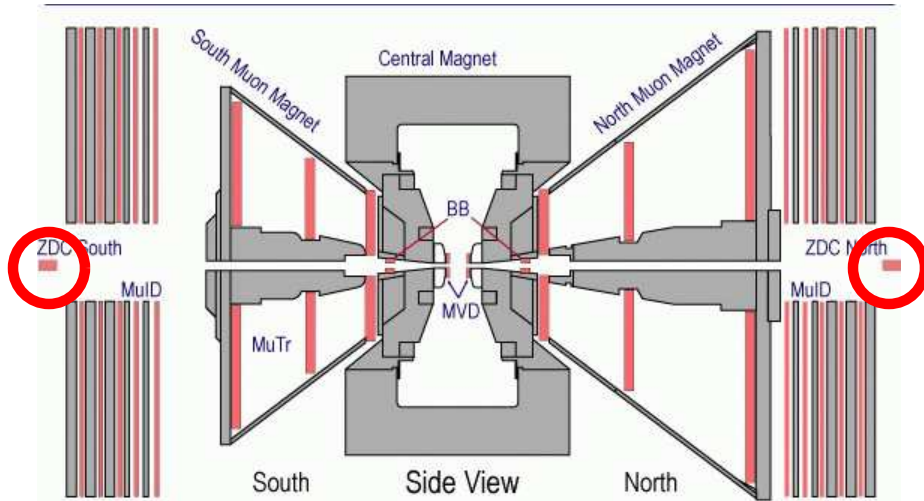
FOM : Figure of merit = $P^4 L$

We had first long longitudinal spin run in 2005.

Figure of merit is 40 times larger than past years.

Local Polarimeter

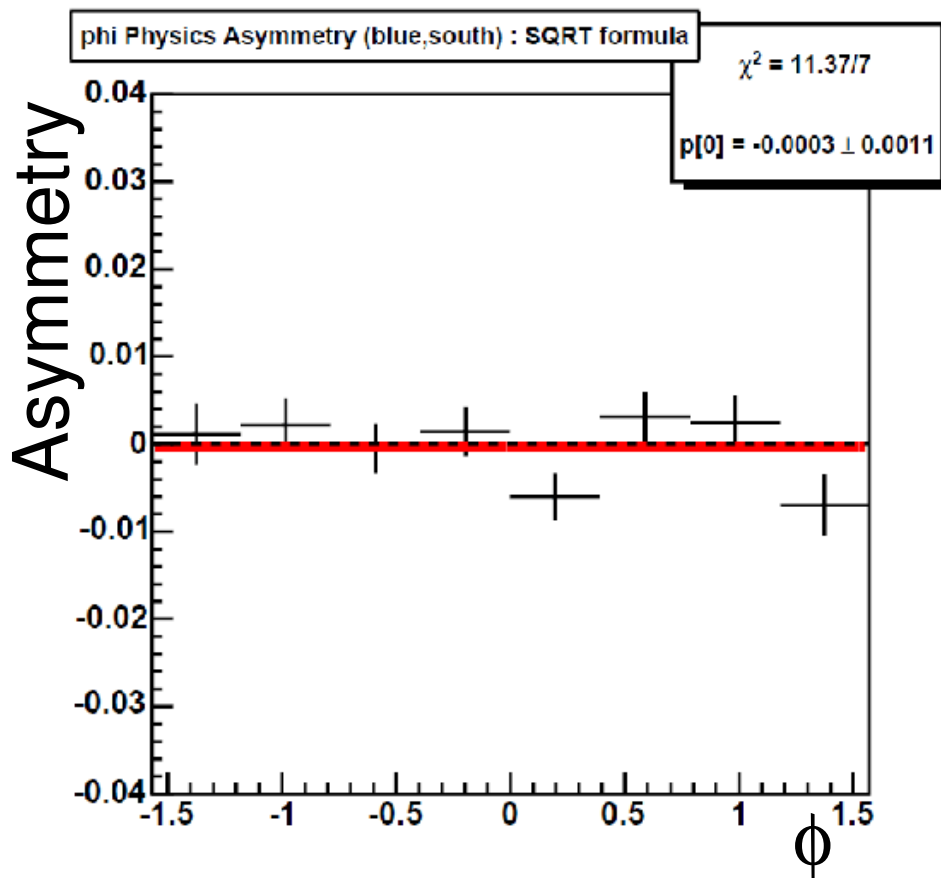
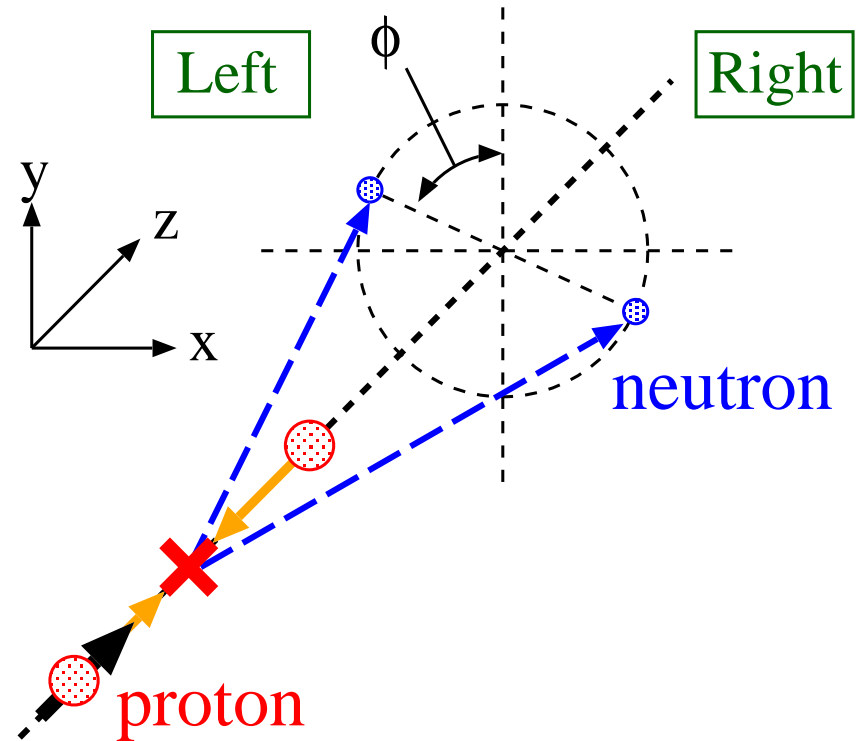
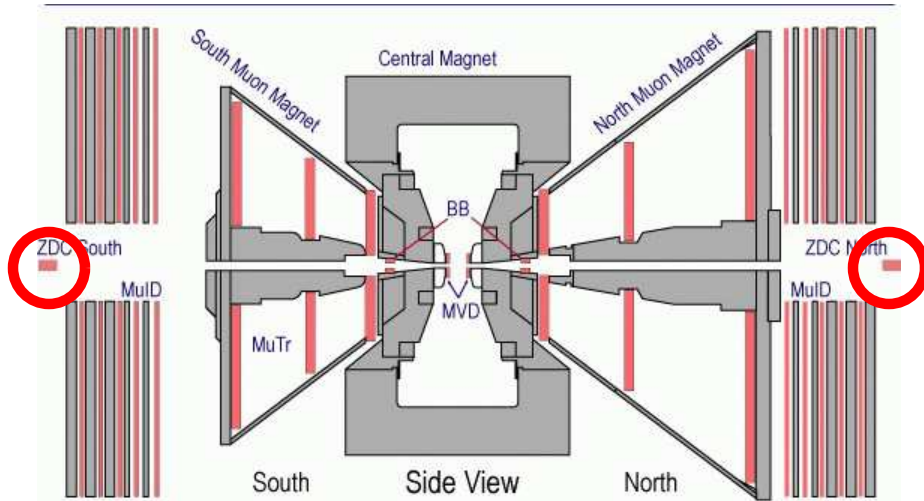
Measure A_N of neutron in very forward region.



Rotator **OFF**
Clear asymmetry is observed.

Local Polarimeter

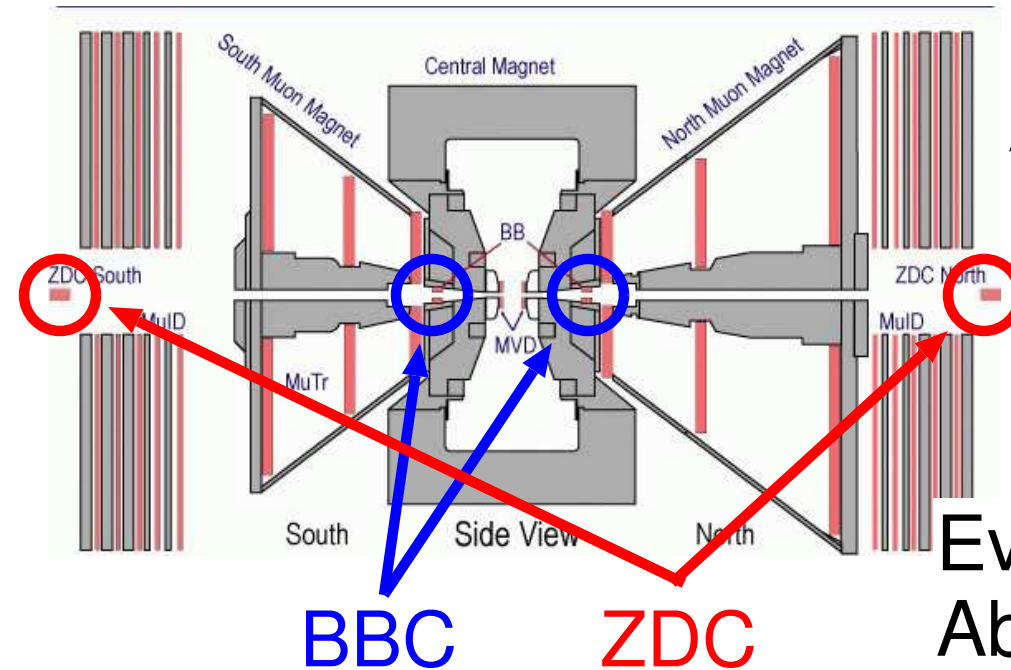
Measure A_N of neutron in very forward region.



Rotator **ON**
Asymmetry disappears.

Longitudinal component $> 98\%$

Relative Luminosity



$$A_{LL} = \frac{1}{P \cdot P} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad R = \frac{L_{++}}{L_{+-}}$$

P : Beam polarization

N : Number of measured particles

R : Relative Luminosity

Events detected by BBC are used.
Absolute scale is not necessary.

Systematic uncertainty evaluation

> Compare two detector with different acceptance.

- BBC : $3.0 < |\eta| < 3.9$
- ZDC : $|\eta| > 6.6$ ($\theta < 2.8$ mrad)

$$r(i) = \frac{N_{ZDC}(i)}{N_{BBC}(i)} \quad \text{should be constant.}$$

(i : crossing number)

Relative Luminosity

Compare two rel. lum. detectors : BBC vs. ZDC

$$r(i) = \frac{N_{\text{ZDC}}(i)}{N_{\text{BBC}}(i)} \text{ should be constant. (} i : \text{ crossing number)}$$

Fit $r(i)$ to $C[1 + \alpha P_B(i)P_Y(i)]$: α is possible asymmetry.

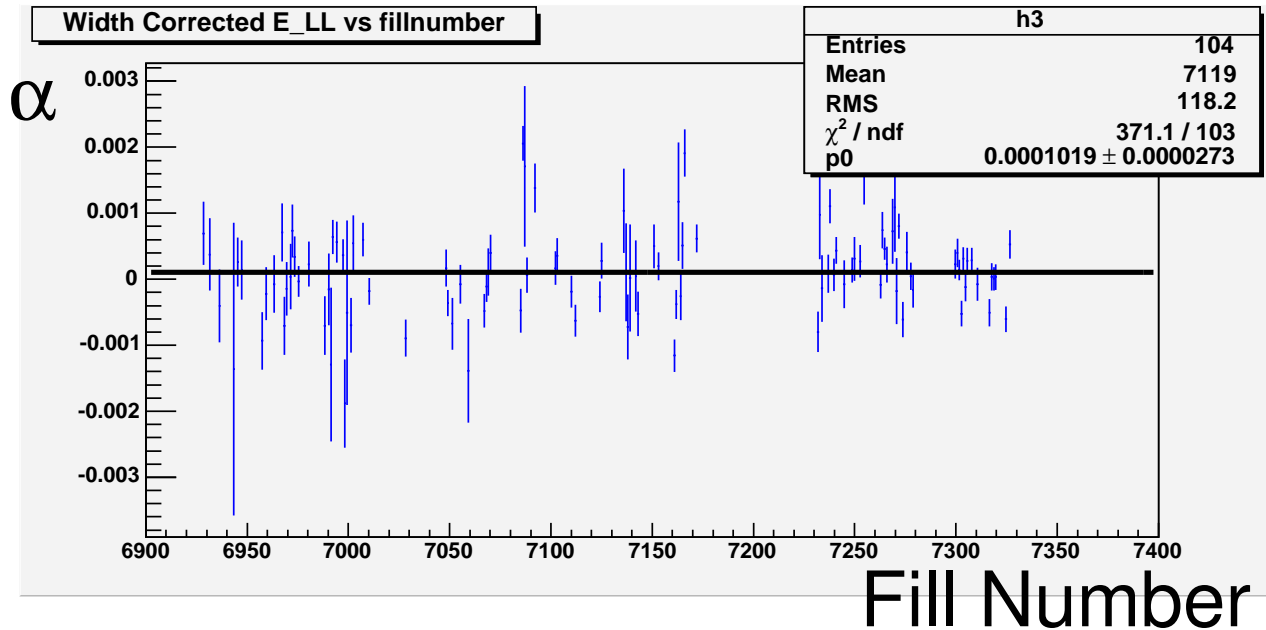
$$\delta A_{\text{LL}} \text{ from rel. lum. is } \frac{\delta R}{2 P_B P_Y} = \frac{\delta \alpha}{P_B P_Y}$$

After renormalization
by chisquare,

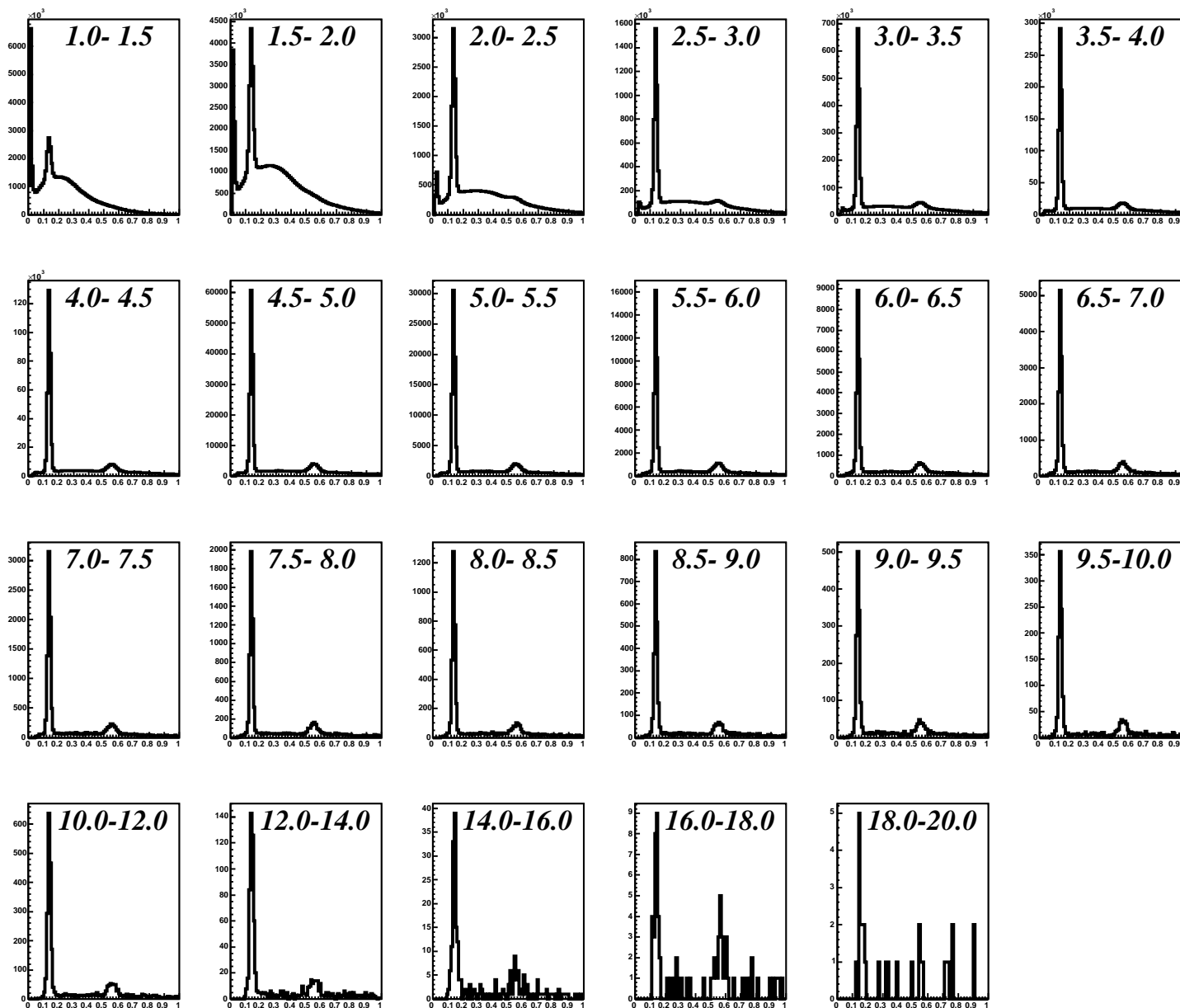
a) $\delta R = 1.0 \times 10^{-4}$

b) $\delta A_{\text{LL}} = 2.3 \times 10^{-4}$
for 47% beam
polarization.

c) A_{LL} of BBC relative
to ZDC is
consistent with 0.



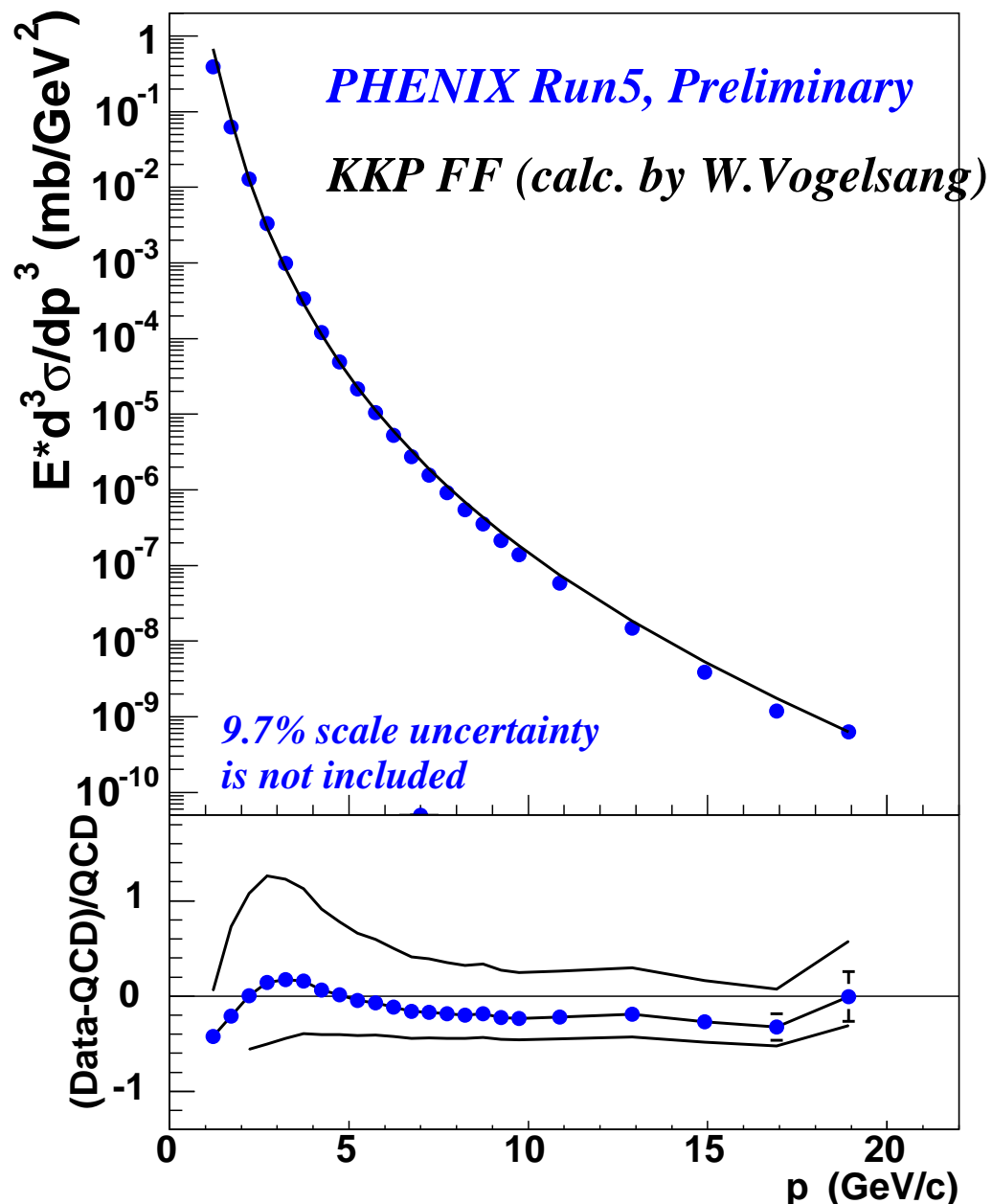
$\gamma\text{--}\gamma$ Mass Spectrum

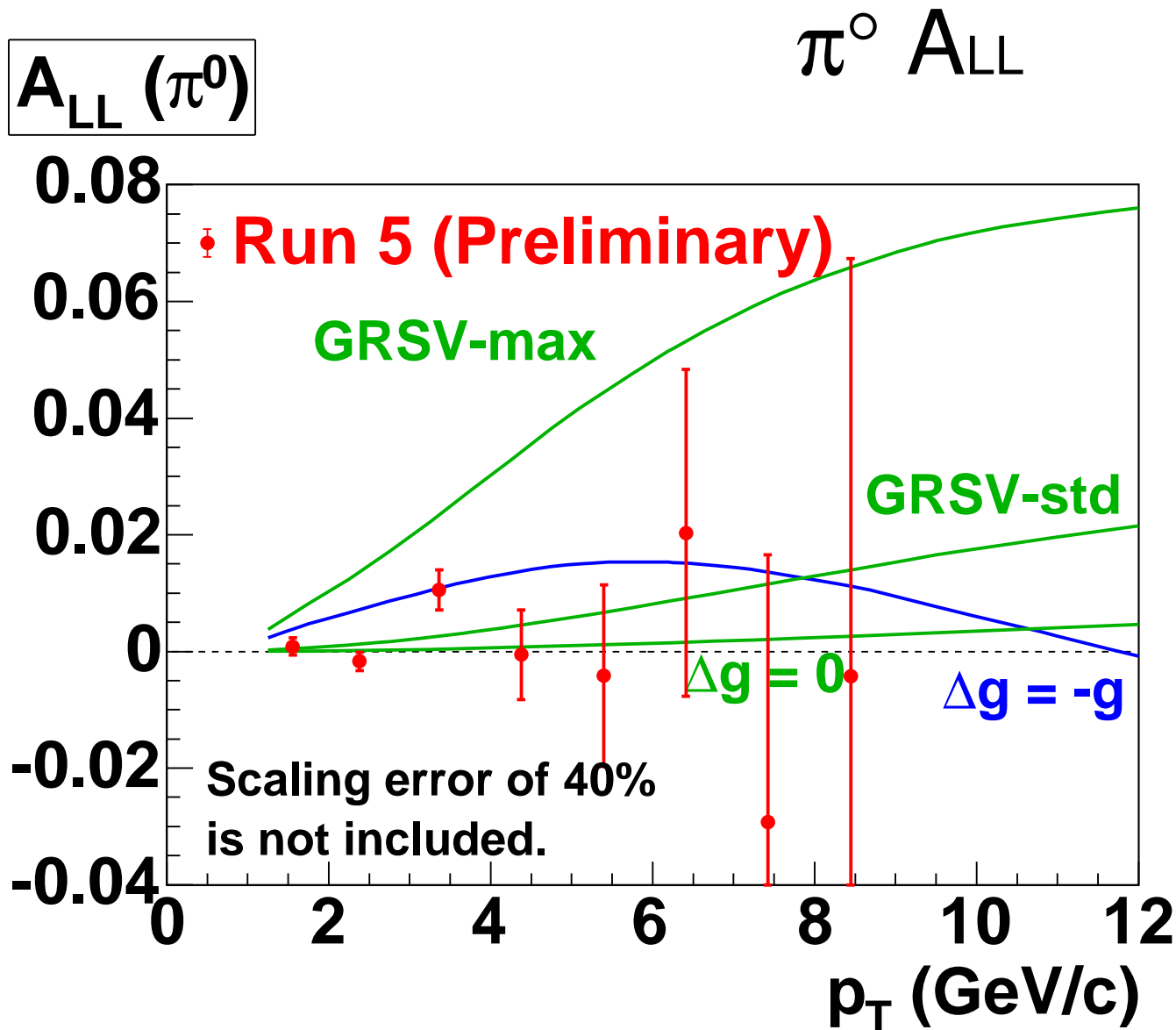


Background fraction is $\sim 30\%$ in 1-2 GeV/c
and $\sim 5\%$ in $p_T > 4$ GeV/c.

π^0 Cross Section

- > The results are consistent with our past data.
- > Data points extend to 20 GeV/c of pT.
- > pQCD calculation describes the data well over all measured pT region. (1 - 20 GeV/c)
- > The cross section of other channel, for example charged pion, is also useful to test pQCD.





Theory Model	C.L. (%)
GRSV-std	21.7-17.1
GRSV-max	0.0-0.0
GRSV $\Delta g = 0$	16.7-18.4
GRSV $\Delta g = -g$	0.7-0.0

Our results reject the GRSV-max.
More statistics is still needed.

But C.L. is dominated by lower p_T bins. That's why we are trying to test pQCD with other channels.

Summary of systematic error

> Relative Luminosity

The error to ALL is 0.023% which is much smaller than statistical error. The error is 0.011% for AL.

> Beam Polarization

20% is assigned as relative systematic error.

This introduces 40% (20%) scale error for ALL (AL).

> Local Polarimeter

$\langle P_L/P \rangle = 99.48 \pm 0.12 \pm 0.02$ (%) for Blue beam

$\langle P_L/P \rangle = 98.94 \pm 0.21 \pm 0.04$ (%) for Yellow beam

This is negligible compared to the error of absolute beam polarization.

> ATT

$\langle P_B P_Y \rangle = 0.22$, $\langle P_{Bx} P_{Yx} \rangle = 0.0022$, $\langle P_{By} P_{Yy} \rangle = 0.0001$

The effect of ATT is suppressed by factor 100 compared to ALL. It is assumed that ATT is smaller than ALL and uncertainty due to ATT is negligible in this case.

We will measure ATT using runs with transverse polarization.

> Bunch Shuffling

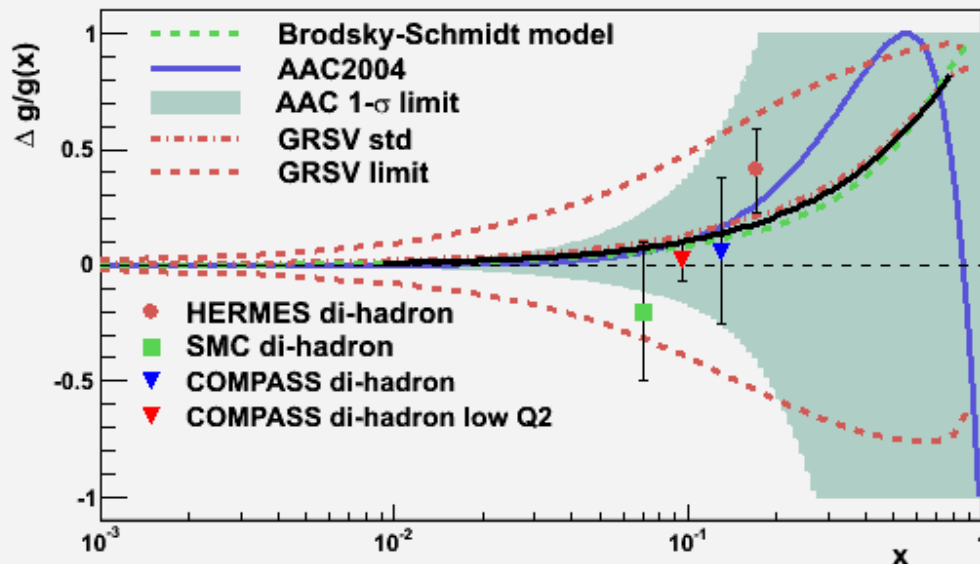
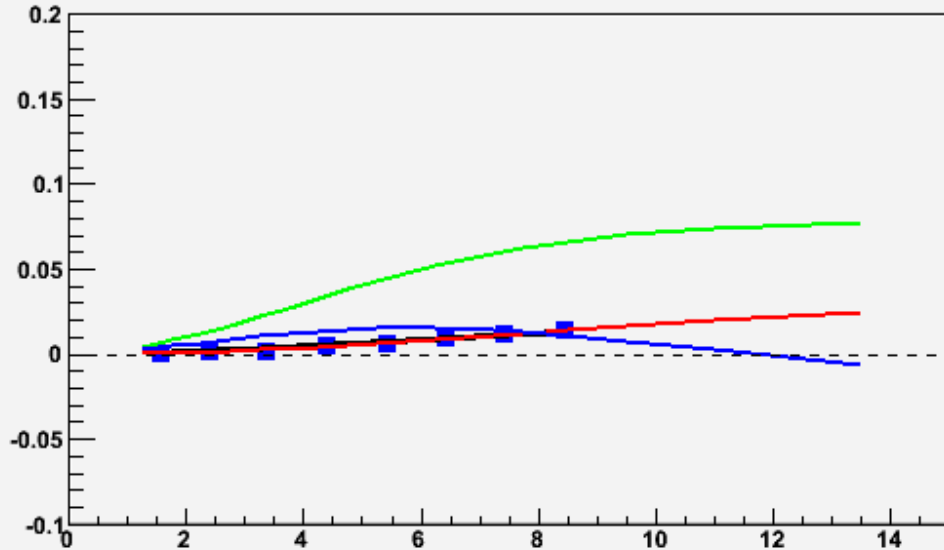
Bunch-to-bunch or fill-to-fill systematic error is negligible compared to statistical error.

ΔG with simple model

$$A_{\text{LL}} \sim a\left(\frac{\Delta g}{g}\right)^2 + b\left(\frac{\Delta g}{g}\right) + c$$

a , b , c and mean x can be extracted from several models of Δg . (Thanks to Marco, Werner et. al.)

a , b and c : depend on pT
 $\left(\frac{\Delta g}{g}\right) = A\langle x \rangle^2$, $\langle x \rangle = f(pT)$



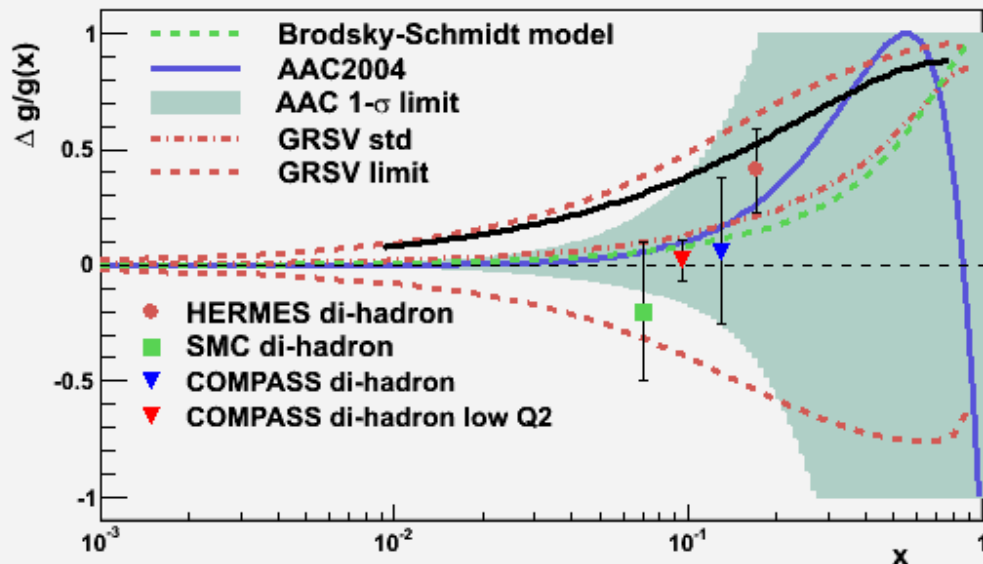
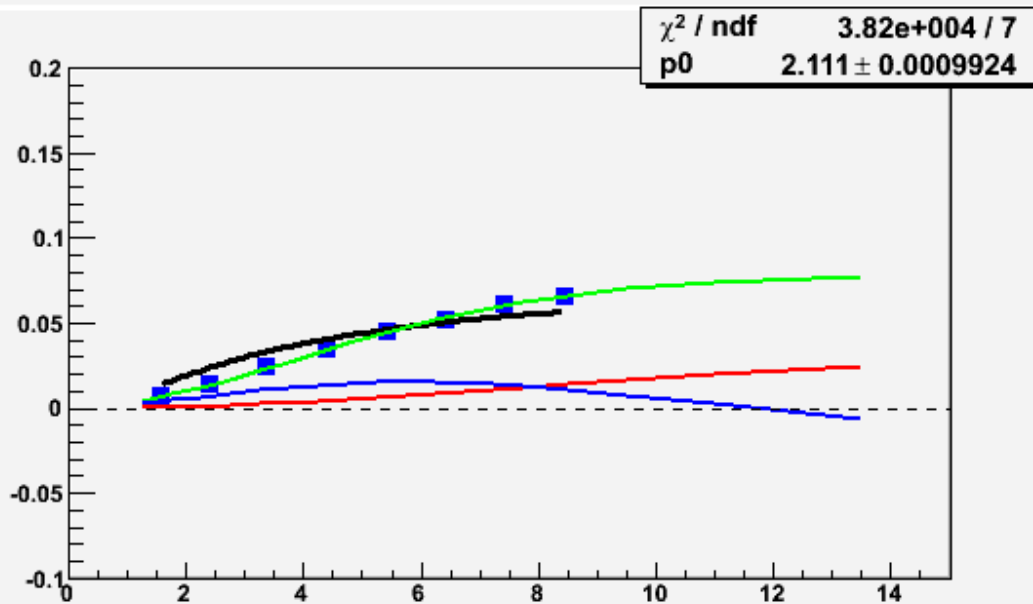
by N. Saito

ΔG with simple model

$$A_{\text{ALL}} \sim a\left(\frac{\Delta g}{g}\right)^2 + b\left(\frac{\Delta g}{g}\right) + c$$

a , b , c and mean x can be extracted from several models of Δg . (Thanks to Marco, Werner et. al.)

a , b and c : depend on pT
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by N. Saito

ΔG with simple model

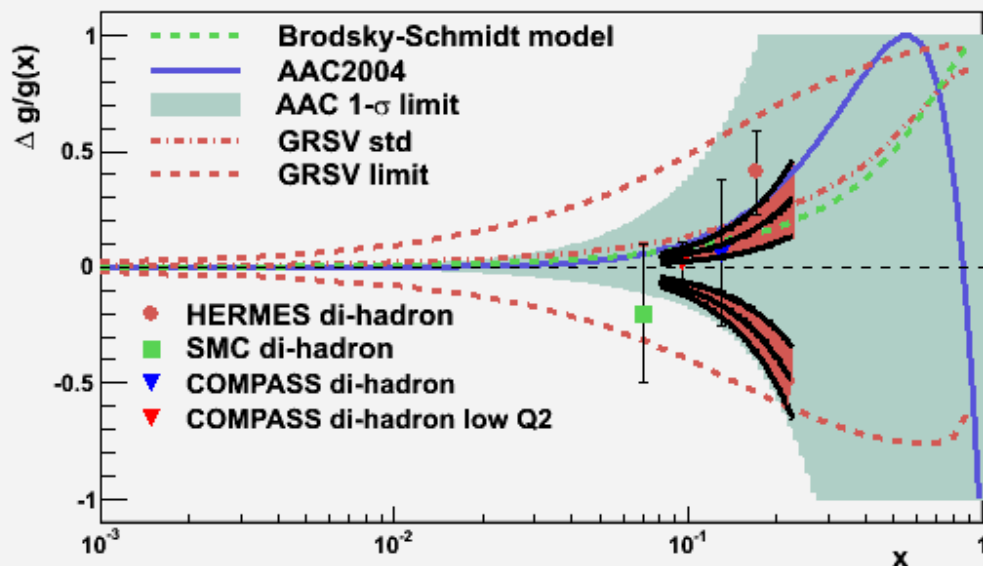
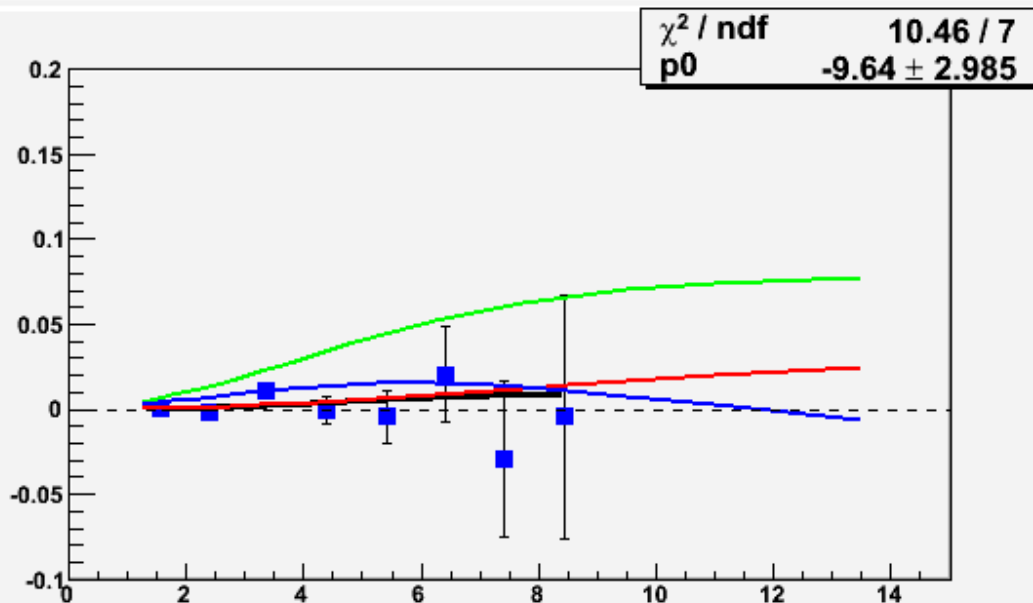
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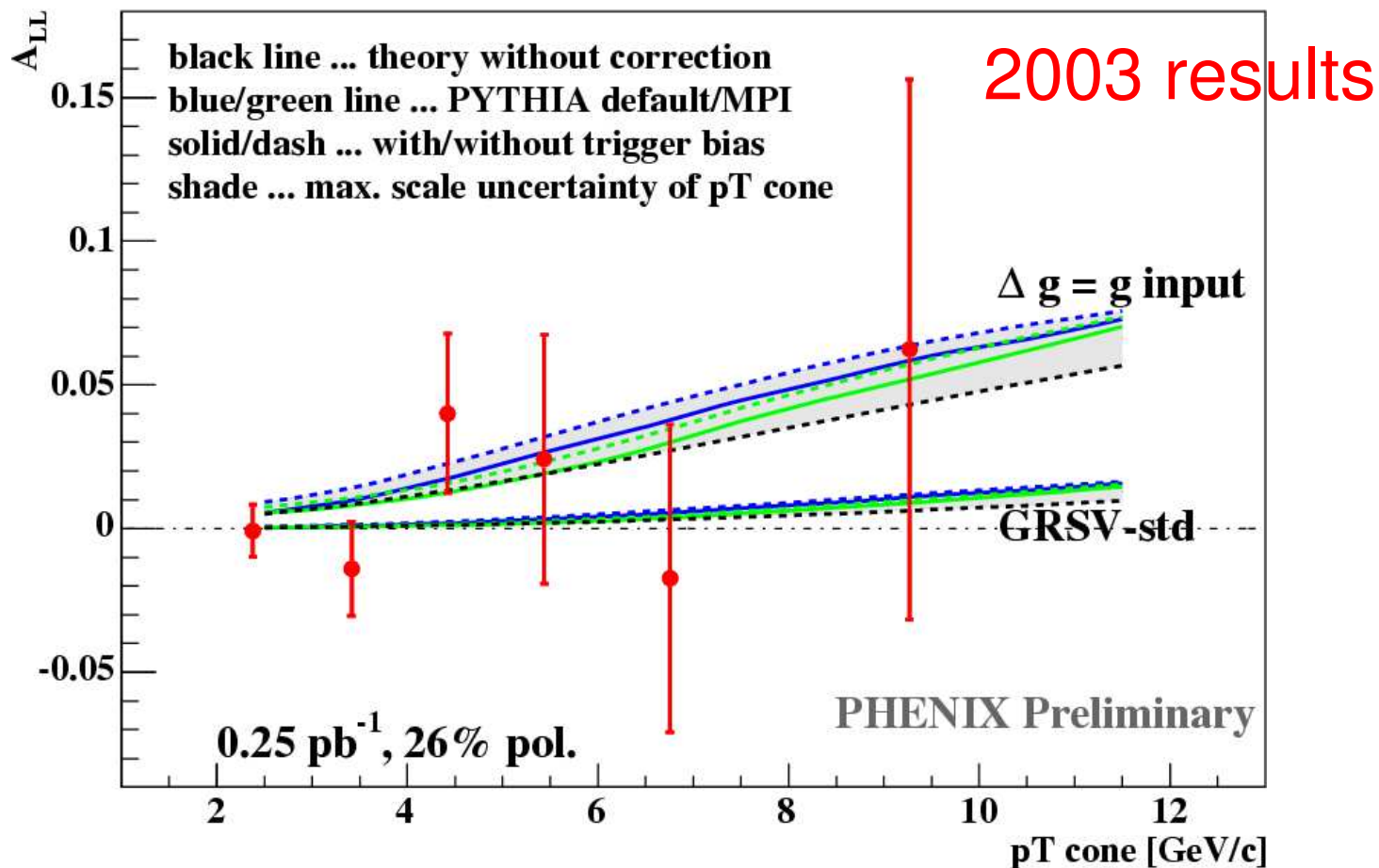
a , b and c : depend on pT
 $\left(\frac{\Delta g}{g}\right) = A\langle x \rangle^2$, $\langle x \rangle = f(pT)$

Positive and negative Δg is obtained due to duality of quadratic equation.

by N. Saito



"Jet" ALL

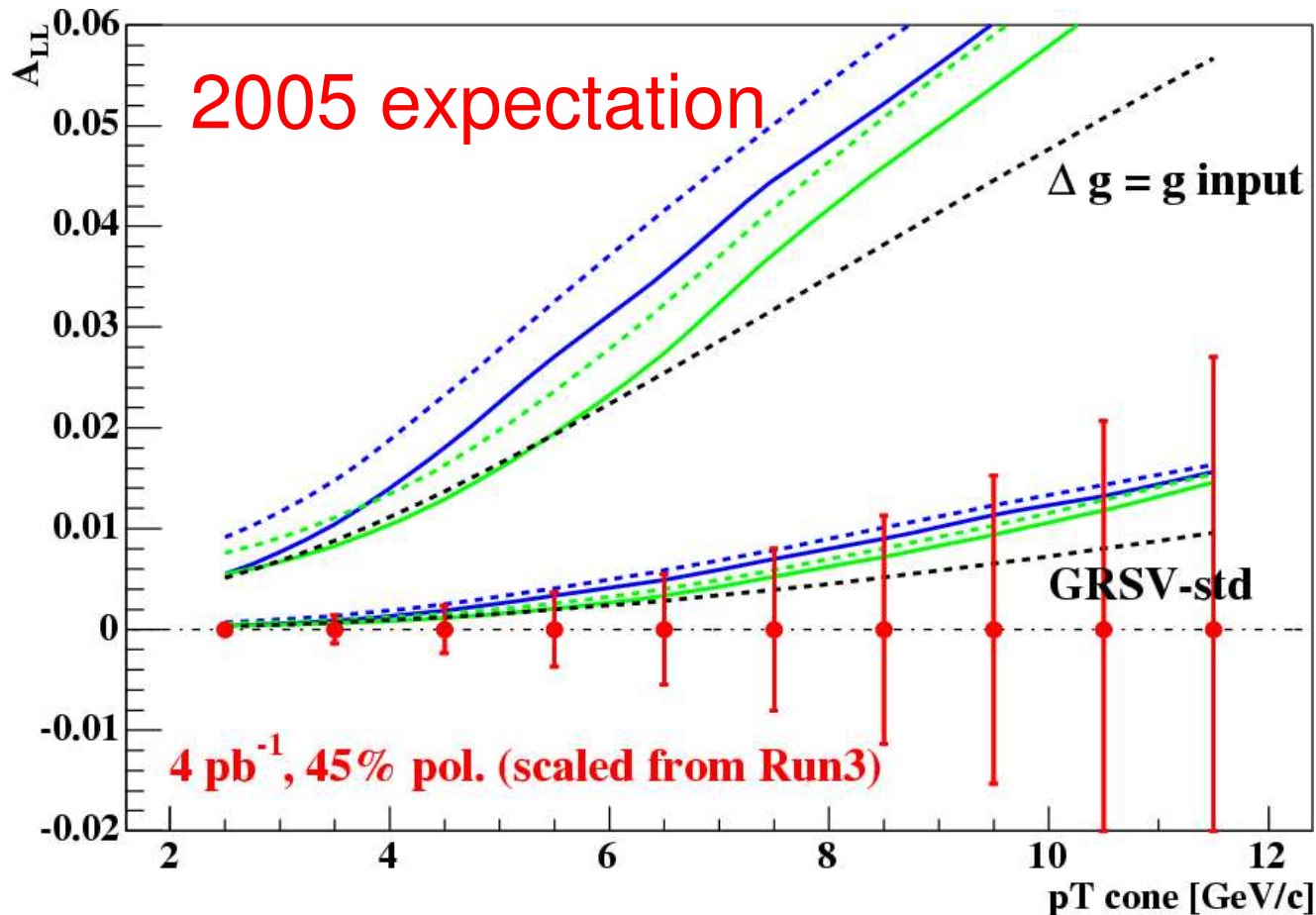


"Jet" detection : Tag one high energy photon and sum energy of nearby photons/charged particles.

Definition of "pT cone" : Sum of pT measured by EMCal & Tracker with $R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$

Real pT of jet is evaluated by modified PYTHIA.

"Jet" ALL

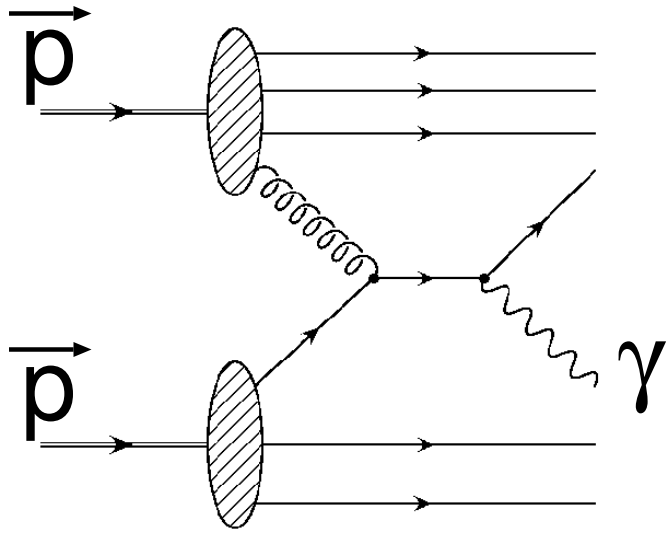


"Jet" detection : Tag one high energy photon and sum energy of nearby photons/charged particles.

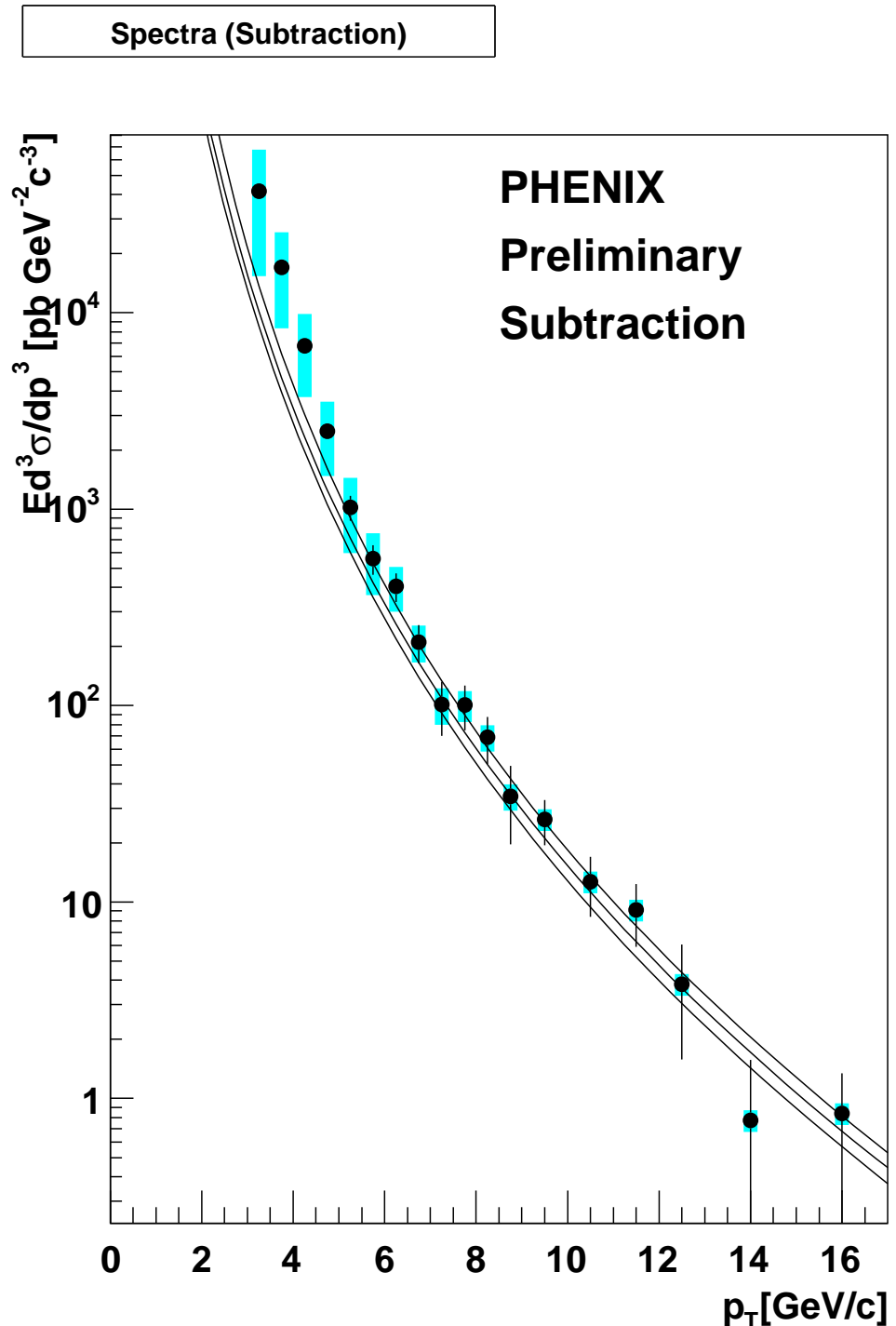
Definition of "pT cone" : Sum of p_T measured by EMCal & Tracker with $R = \sqrt{|\phi|^2 + |\eta|^2} < 0.3$

Real p_T of jet is evaluated by modified PYTHIA.

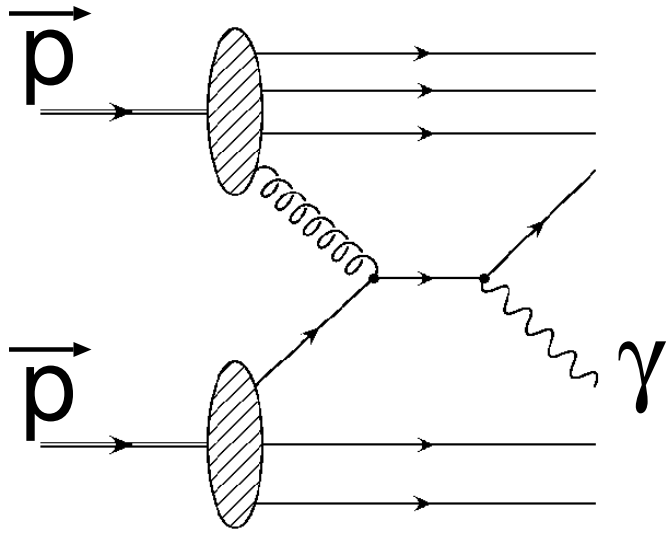
Direct photon



- > Independent from fragmentation.
- > ALL is linear equation of Δg .
Sensitive to sign of Δg
- > Low statistics
- > Theory describes data well at $p_T > 5$ GeV/c.
(cross section)

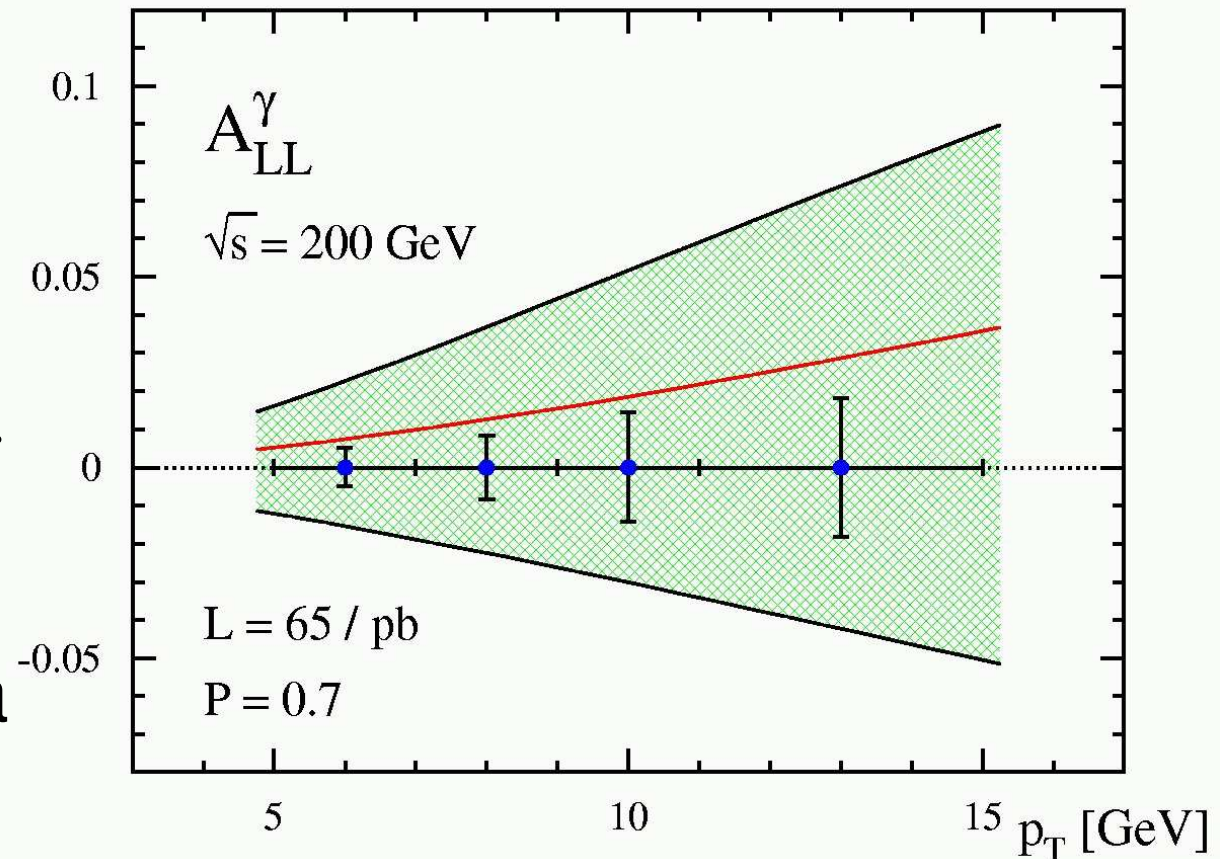


Direct photon



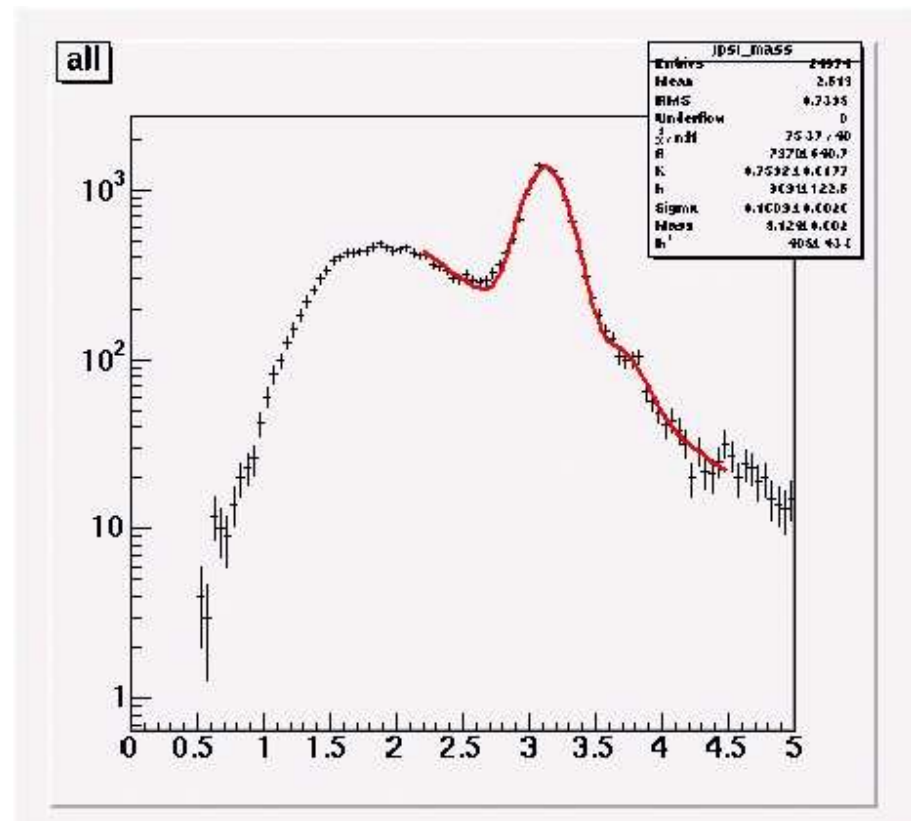
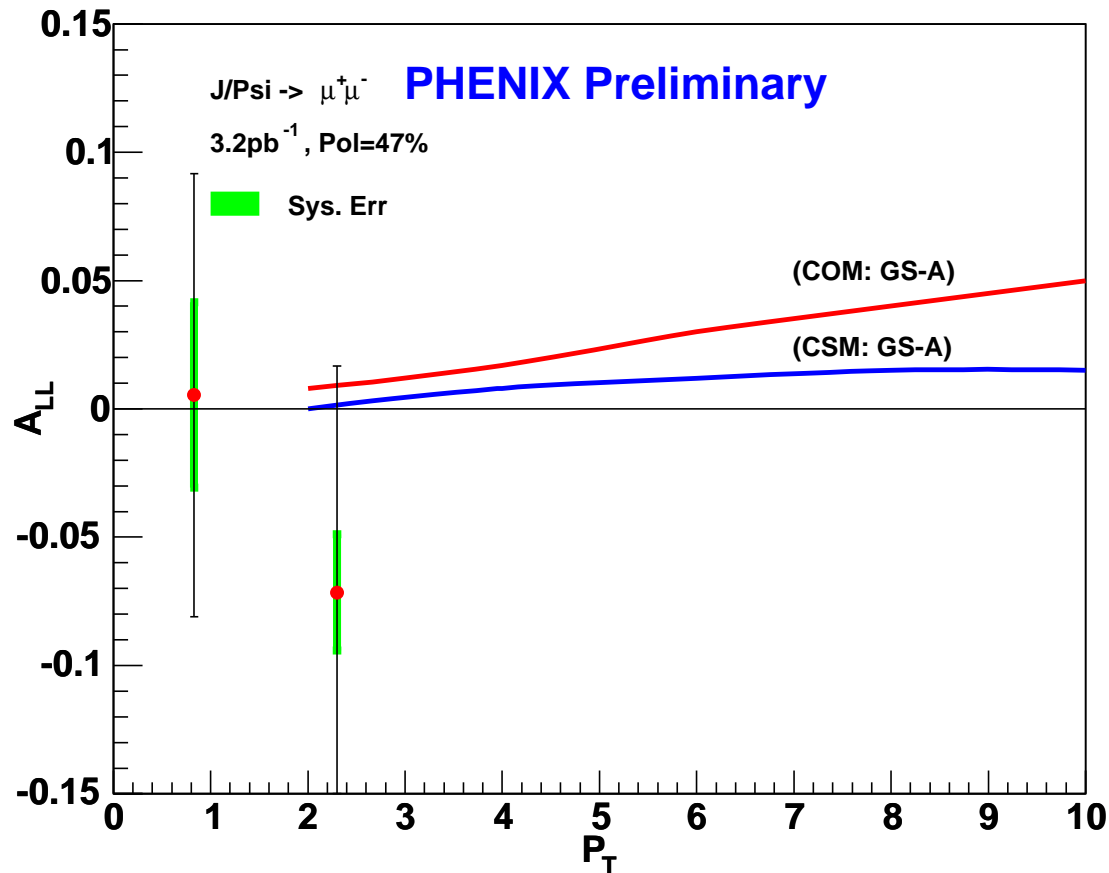
We can constrain Δg with direct photon in near future.

- > Independent from fragmentation.
- > ALL is linear equation of Δg .
Sensitive to sign of Δg
- > Low statistics
- > Theory describes data well at $p_T > 5$ GeV/c.
(cross section)



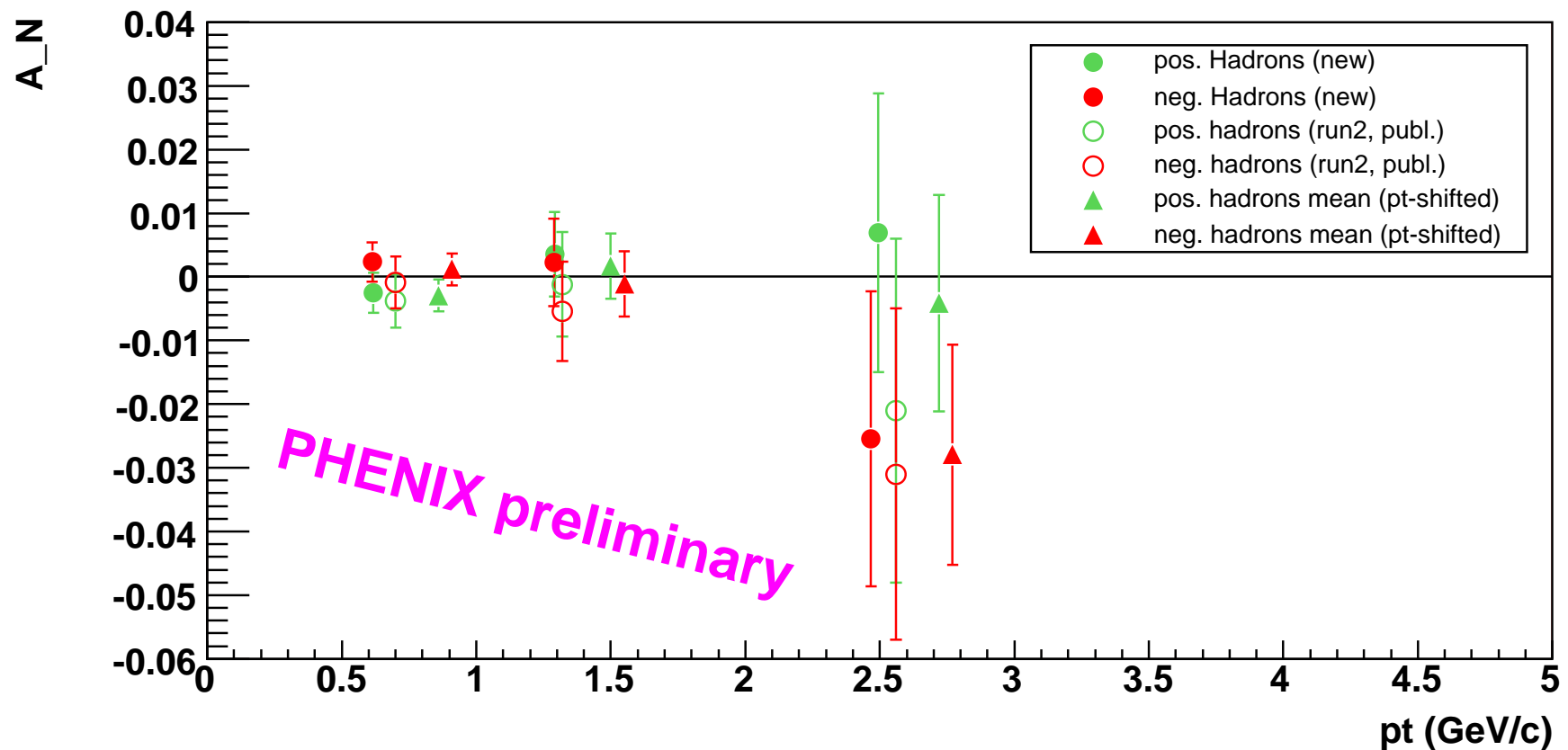
J/ψ

J/Psi: $|\eta| = 1.2-2.4$



- > Measurement is done using muon arm ($1.2 < |\eta| < 2.4$)
- > More statistics is needed.
- > A_{LL} depends on the production mechanism of J/ψ.

Charged pions (A_N)



- > PHENIX can measure charged hadrons and pions in central region.
- > ALL of charged pions will constrain Δg in addition to π^0 results.
- > Cross section measurement is another test for the validity of pQCD.

Summary

- > PHENIX has taken first long longitudinal-spin polarized-proton collision data in Run-5 (2005).
 - > 40 times more statistics in figure of merit for ALL.
- > Basic tools (Local polarimeter, Relative luminosity measurement) to obtain ALL are established.
The systematic uncertainties from them are smaller than statistics of π^0 .
- > Δg measurement
 - GRSV-max is rejected by π^0 data.
 - Δg is extracted with simple model using π^0 data.
 - Jet ALL in run 5 can be another probe for Δg .
 - Study with other channels are on going. (γ , J/ψ , π , η , λ)
- > To cover wider x range,
 - More statistics in higher pT for large x.
 - Collision at $\sqrt{s} = 500$ GeV for lower x.

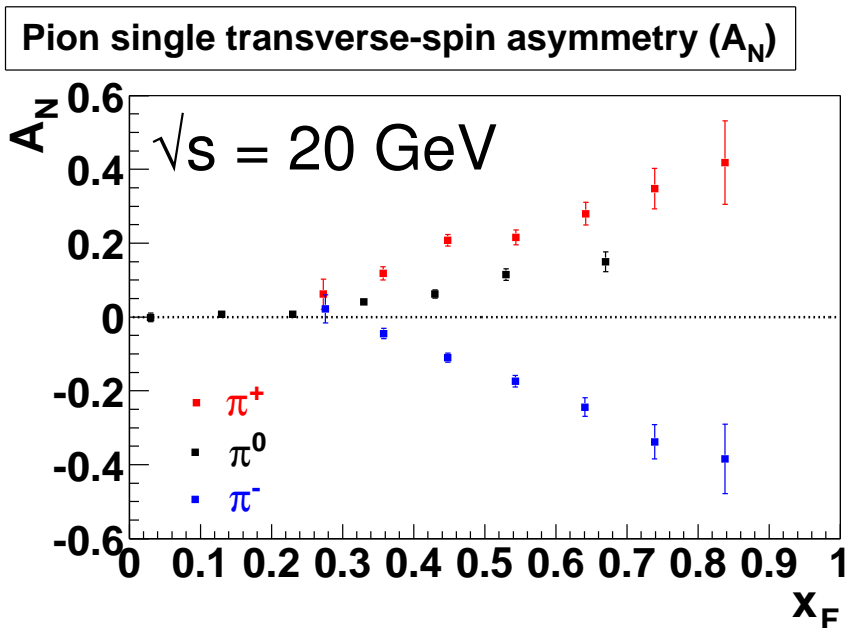
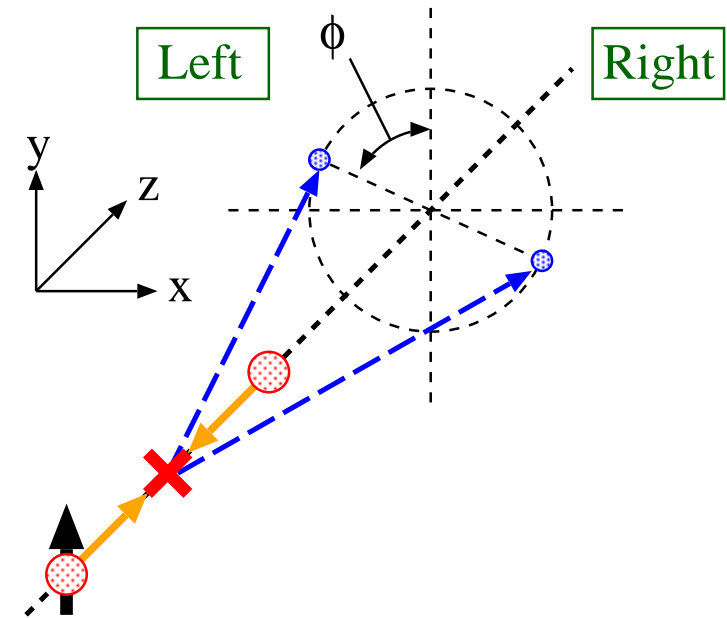
Spin Physics at RHIC-PHENIX

Single Transverse Spin Asymmetry

Left - right asymmetry by transversely polarized beam.

$$A_N = \frac{1}{\sin(\phi)} \frac{\sigma(\phi) - \sigma(\phi - \pi)}{\sigma(\phi) + \sigma(\phi - \pi)}$$

Several approaches are suggested.
(Collins effect, Sivers effect, Twist-3...)



> A_N of pions is measured by many experiment.
(E704, STAR, BRAHMS)

> A_N of pion, neutron is measured by PHENIX

Spin Physics at RHIC-PHENIX

Anti-quark distribution ($\Delta\bar{q}$) with W

W coupling is flavor sensitive.

($u\bar{d} \rightarrow W^+$, $\bar{u}d \rightarrow W^-$)

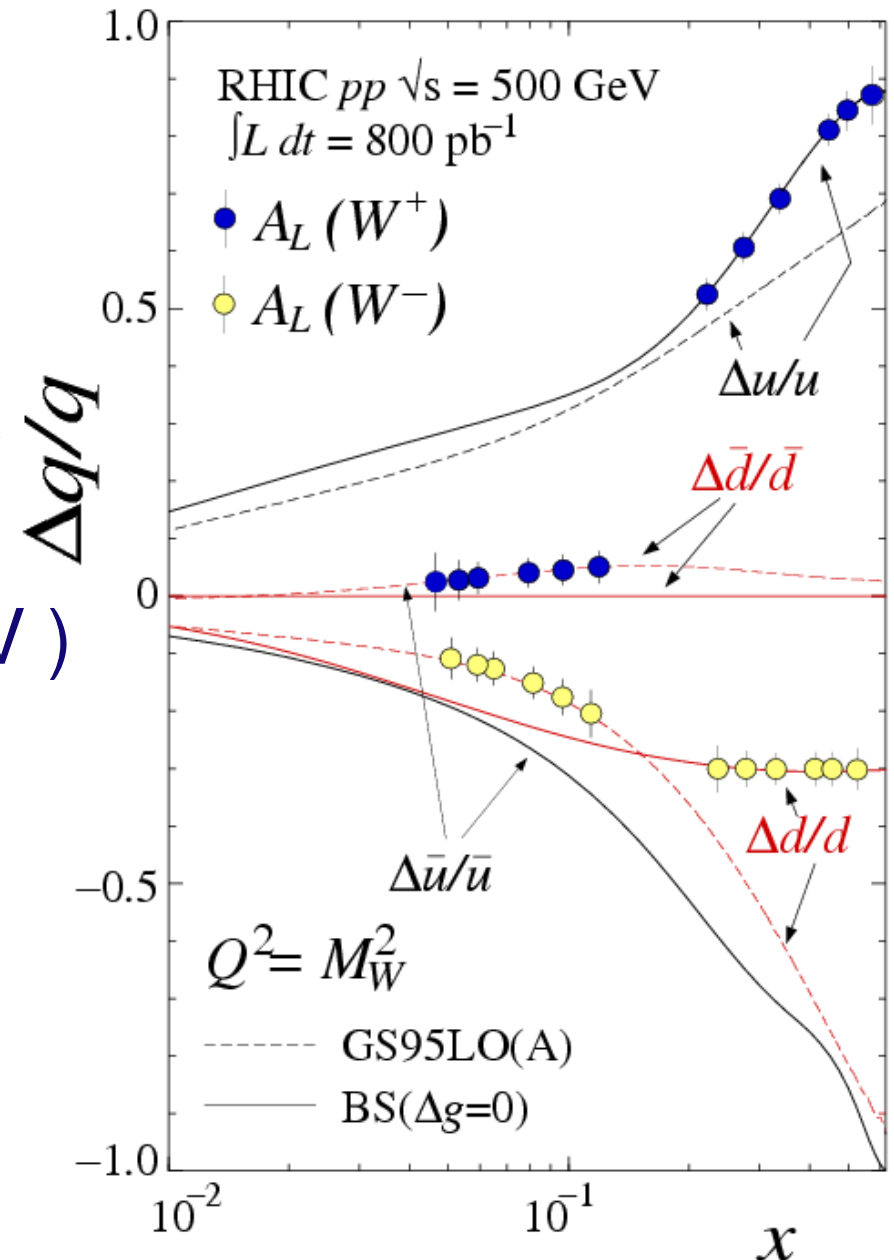
---> Anti-quark distribution can be extracted.

The operation with $\sqrt{s} = 500$ GeV is planned in the future.
(Currently basic setup is 200 GeV)

Measure parity violating A_L .

$$A_L(W^+) = \frac{\Delta u \cdot \bar{d} - \Delta\bar{d} \cdot u}{\Delta u \cdot \bar{d} + \Delta\bar{d} \cdot u}$$

$$A_L(W^-) = \frac{\Delta d \cdot \bar{u} - \Delta\bar{u} \cdot d}{\Delta d \cdot \bar{u} + \Delta\bar{u} \cdot d}$$

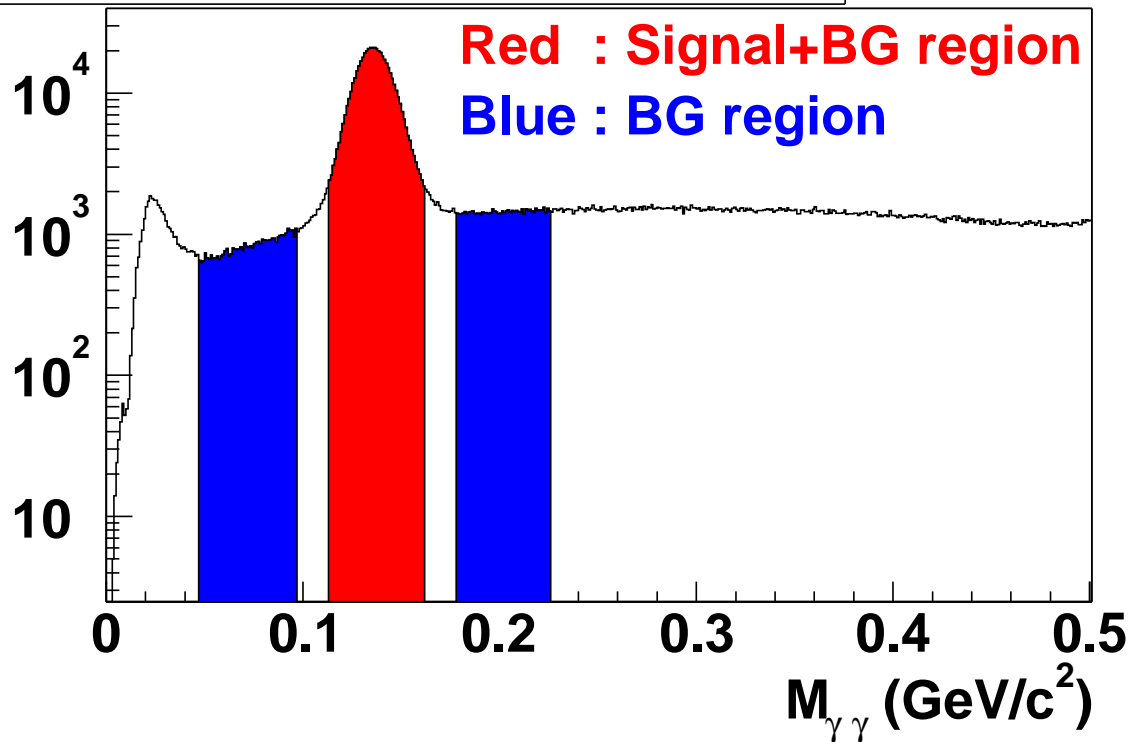


How to calculate π^0 A_{LL}

1. Calculate $A_{LL}(\pi^0+BG)$ and $A_{LL}(BG)$ separately.
2. Get background ratio (w_{BG}).
3. Subtract $A_{LL}(BG)$ from $A_{LL}(\pi^0+BG)$

$$A_{LL}(\pi^0+BG) = w_{\pi^0} \cdot A_{LL}(\pi^0) + w_{BG} \cdot A_{LL}(BG)$$

Two photon invariant mass



π^0+BG region :
 ± 25 MeV
around π^0 peak

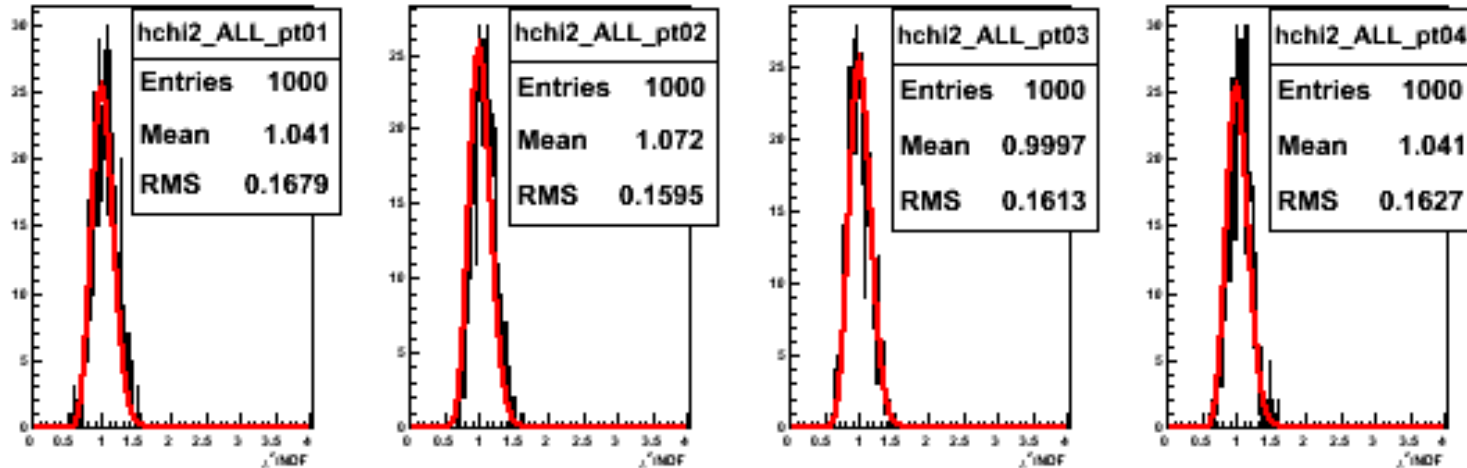
BG region :
Two 50 MeV region
around π^0 peak

Syst. error estimation by Bunch Shuffling

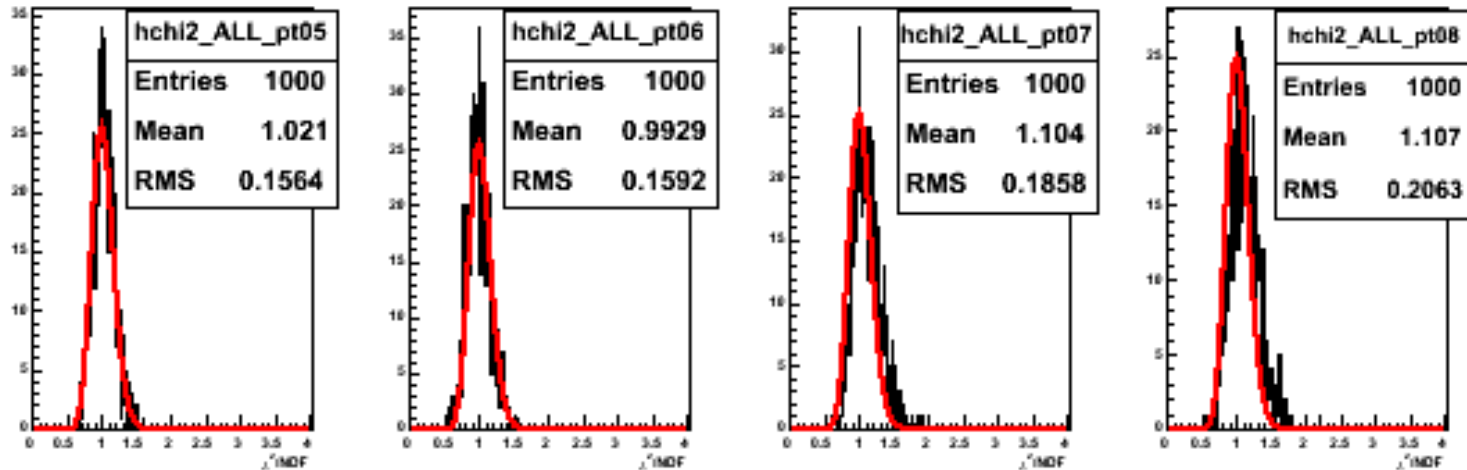
Randomly assigns helicity for each crossing.

Check chisquare from fitting fill vs. ALL.

1 < pT < 2 GeV/c 2 < pT < 3 GeV/c 3 < pT < 4 GeV/c 4 < pT < 5 GeV/c



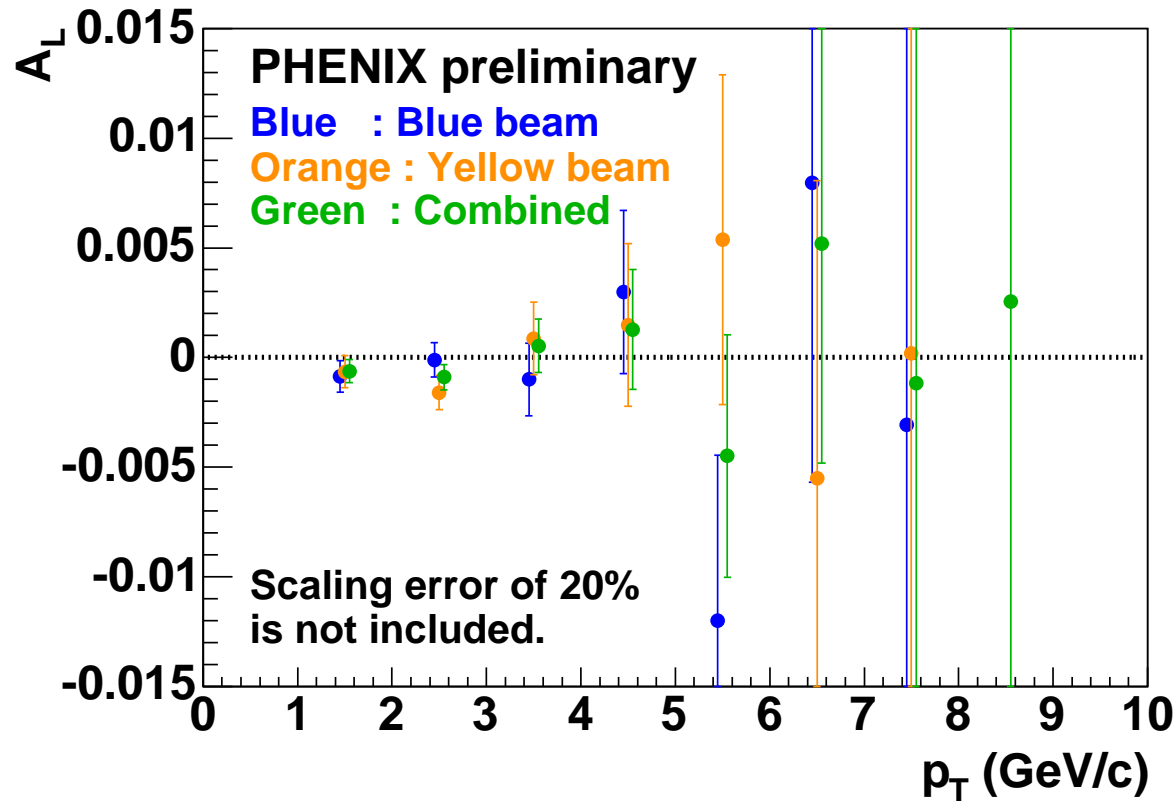
5 < pT < 6 GeV/c 6 < pT < 7 GeV/c 7 < pT < 8 GeV/c 8 < pT < 9 GeV/c



χ^2/NDF distributions have good agreement with ideal curve.

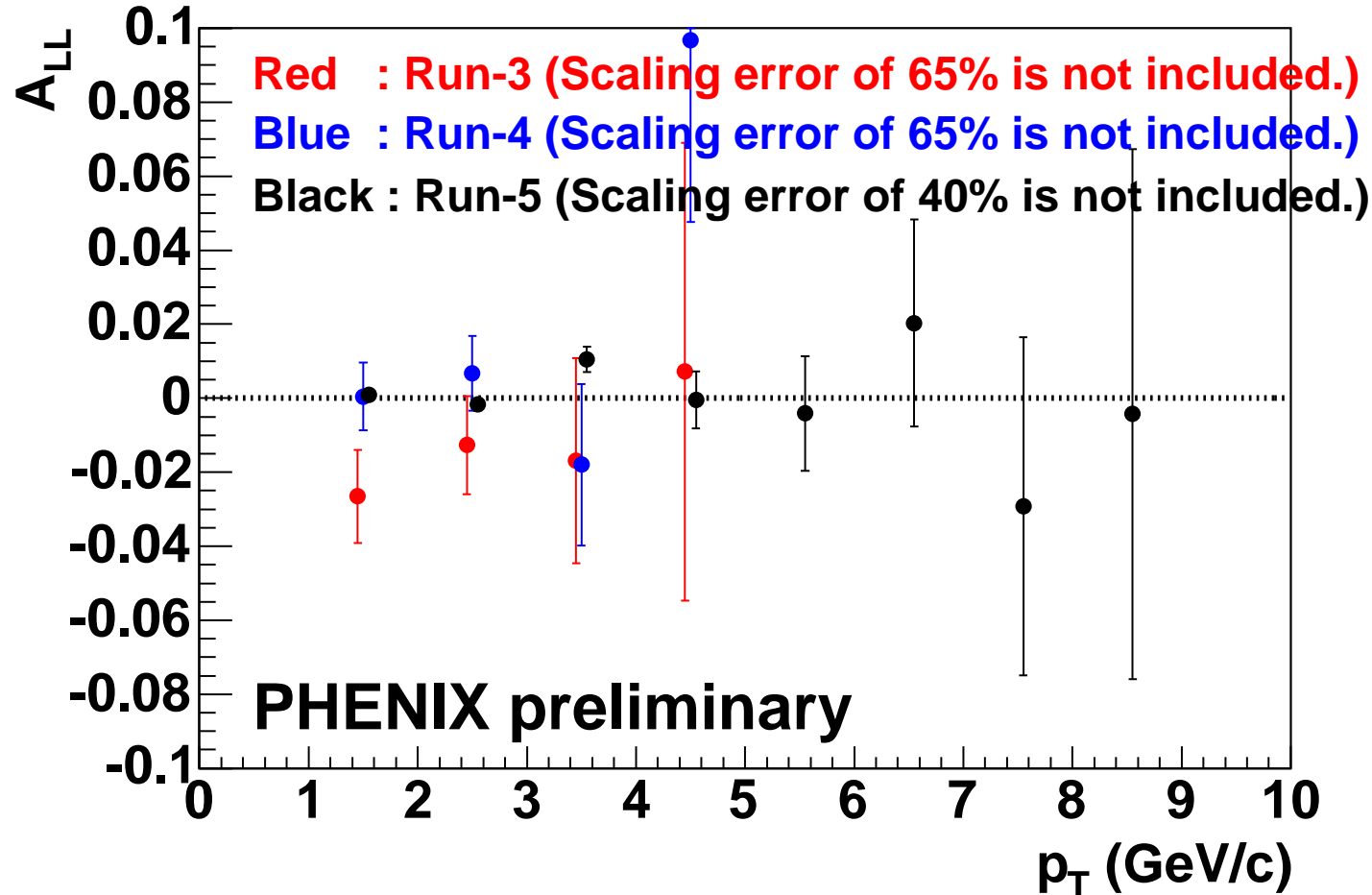
All bunch/fill dependent syst. error are negligible.

AL and other check



- > A_L ---> Consistent with 0
- > Parity violation A_{LL} : σ_{++} vs. σ_{--} , σ_{+-} vs. σ_{-+}
---> Consistent with 0 as expected.
- > Various mass range. (± 15 MeV, ± 35 MeV)
---> Results are consistent.

ALL comparison with Run3/4



C.L. between Run5 and Run3/4 is

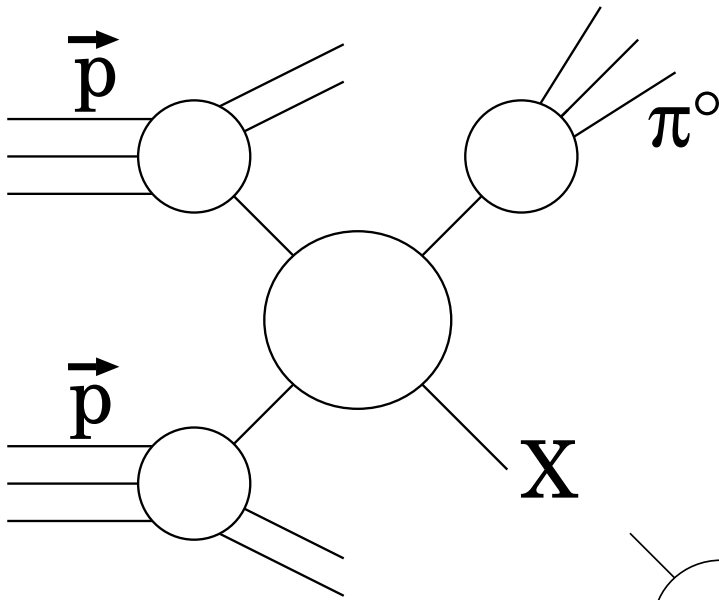
> Run3 : 17.6 %

> Run4 : 18.7 %

They are consistent. (Scale error is not considered.)

Spin Physics at RHIC-PHENIX

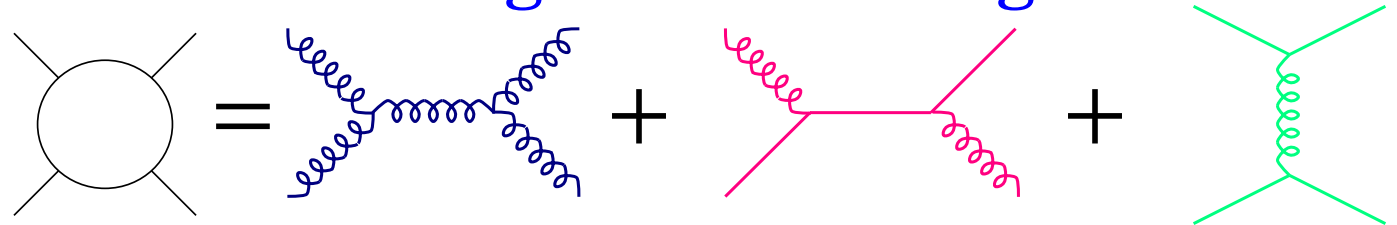
How to measure Δg



Measure A_{LL} in $\vec{p} \vec{p} \rightarrow X$ production.

$$A_{LL} = \frac{\sigma_{++} - \sigma_{+-}}{\sigma_{++} + \sigma_{+-}}$$

$$\sim [\omega_{gg}] \left(\frac{\Delta g}{g} \right)^2 + [\omega_{gq} \Delta q] \left(\frac{\Delta g}{g} \right) + [\omega_{qq} (\Delta q)^2]$$



In the experiment, we calculate

$$A_{LL} = \frac{1}{P \cdot P} \frac{N_{++} - RN_{+-}}{N_{++} + RN_{+-}} \quad R = \frac{L_{++}}{L_{+-}}$$

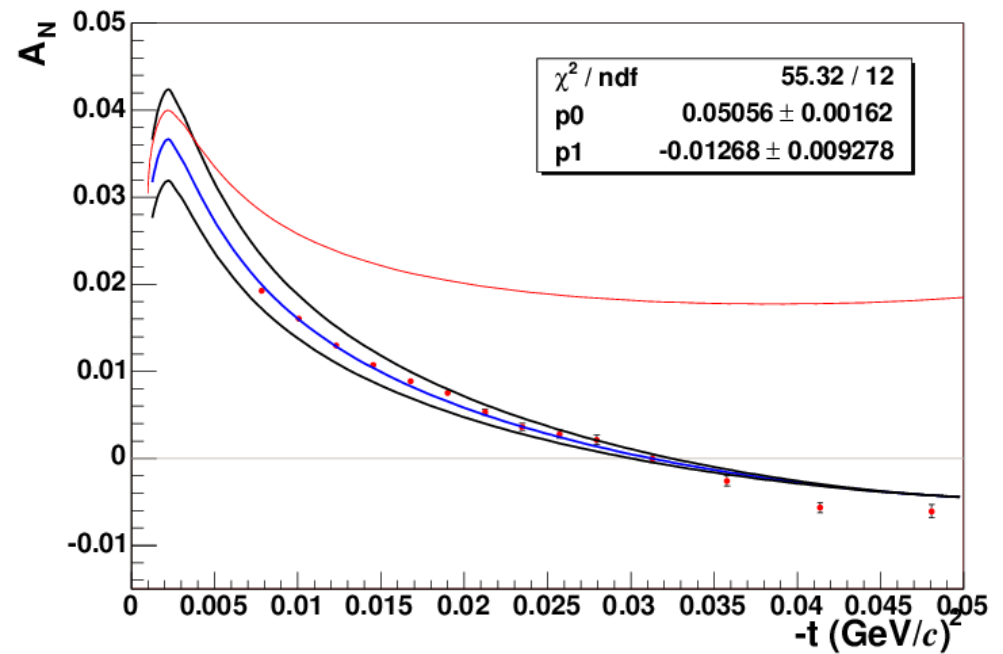
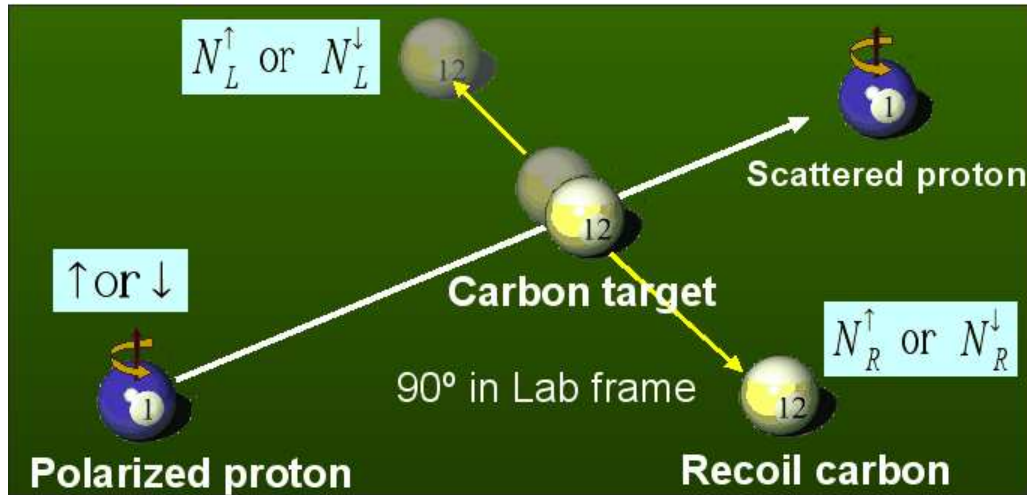
N : Number of particle measured in each helicity state.

P : Beam polarization.

R : Relative Luminosity

Polarimeter

proton-Carbon polarimeter



Polarized proton gas jet polarimeter

